OPTICAL TECHNOLOGY
APOLLO EXTENSION SYSTEM
PART I

SUMMARY REPORT

CONTRACT NAS 8-20256

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SPACE DIVISION CHRYSLER CORPORATION

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PART I

SUMMARY REPORT

CONTRACT NAS 8-20256

October 21, 1966

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PREFACE

The final report of the Optical Technology Apollo Extension System prepared for NASA/Marshall Space Flight Center under Contract Number NAS8-20256 is presented in three volumes. The study was a team effort by Chrysler Corporation Space Division (prime contractor), Kollsman Instrument Corporation, and Sylvania Electronics Systems.

The OTAES team gratefully acknowledges the help given by the NASA Ad Hoc working group during the course of this study.

SUMMARY REPORT

THE OPTICAL TECHNOLOGY APOLLO EXTENSION SYSTEM

I. INTRODUCTION

Scientists, fascinated by the potential of space, have been preparing for space science long before the potential was close to becoming a reality. Leo Goldberg[1] says that his first encounter with space astronomy was in 1937 at the Harvard College Observatory where M. N. Saha described the advantages of solar observations from space.

More recently, the advantages of space for a host of scientific disciplines have become well known. But realizing these advantages requires more than moving ground-based technology to space. New technology must be developed. A key area in this development is space optics. The study reported herein attempts to identify the technological requirements for space optics and to present a blueprint for an orderly and logical development of this technology.

Telescope

One of the most important and versatile of optical tools is the telescope. Traditionally, it is the astronomer's tool. But in space the telescope extends into other fields – meteorology, communications, and earth remote sensing. For many of the planned future space missions, the basic instrument will be a large orbiting telescope. Today, it is possible to build and orbit a large telescope around the earth; but before spending the great amount of time and money necessary for this project, consideration should be given to the design and supporting systems of such a telescope. Questions remain unanswered today. How would various mirror constructions and materials react to the thermal and zero gravity space conditions? What is the best way to stabilize a telescope in space? And what are the special problems that each method of stabilization will raise? To identify the optical problems and to begin to propose solutions to these optical problems will take not only years of study, but also years of experimentation both on the ground and in space.

OTAES

The Optical Technology Apollo Extension System study, which is directed specifically to optical technology, attempts to provide NASA with a plan for technology development in optics. The study outlines the problem areas of optical technology, develops various solutions, and presents the means of implementing the solutions. Some technology can be developed and fully evaluated on the ground; but to achieve complete evaluation for other technology, the development program must include space testing.

Where space testing is a necessary step in technological development, the OTAES study proposes such space experiments. The ground research program coupled with

(1) Leo Goldberg, "The New Astronomies", International Science and Technology, August 1965, pp. 18-28.

the successful completion of these experiments will make it possible to transform today's scientific objectives into tomorrow's realities.

Approach

The technical approach of the OTAES study has been to proceed logically step by step, starting with future NASA objectives and ending with a development plan which, if followed, will lead to the ability to achieve the projected NASA scientific objectives.

The steps are:

1. Determine and document future NASA objectives in the application areas of astronomy, meteorology, earth remote sensing, and optical communications. Scientific articles and industrial reports were the sources for the objectives.

2. Determine the possibility of satisfying the objectives with present technology. If not possible, determine the areas where optical technology development is required to improve present instruments or create new instruments which will satisfy the objectives.

3. Develop space experiments which, if successful, will advance optical technology. Justify each experiment on its own merits in terms of:

   (a) Contribution and need.
   (b) Need for space testing.
   (c) Feasibility.

   Some experiments were considered, and it was determined that they did not require space testing. However, they are still important to the development of optical technology. The ground development program of these experiments and the reasons why they do not require space testing were developed.

4. Analyze each experiment in terms of its impact on the other experiments and the entire OTAES system; for example, consider each experiment in terms of thermal control and power. This leads to evaluation of different means of operation and recommendation of preferred systems.

5. Develop an overall technology plan which will start at the present day and end when the technology level satisfies the objectives of step 1. Included in the plan are key development milestones in the earth-based program, schedules for each individual experiment, and master plan alternatives for the overall OTAES.

II. OPTICAL TECHNOLOGY NEEDS

To establish general optical technology requirements, each of the four application areas, astronomy, meteotology, earth remote sensing, and optical communications, was analyzed in terms of both observational objectives and the technological needs to satisfy these objectives. Figure II-1 shows the results of this analysis. The relationship between technology requirements and individual observations associated with the four application areas is given.

By comparing technology requirements to support the observations with the state-of-the-art capabilities, the deficiencies are used to generate the required technological development. The major purpose of this study has been to determine the required technological development and to formulate a plan whereby this development is achieved.

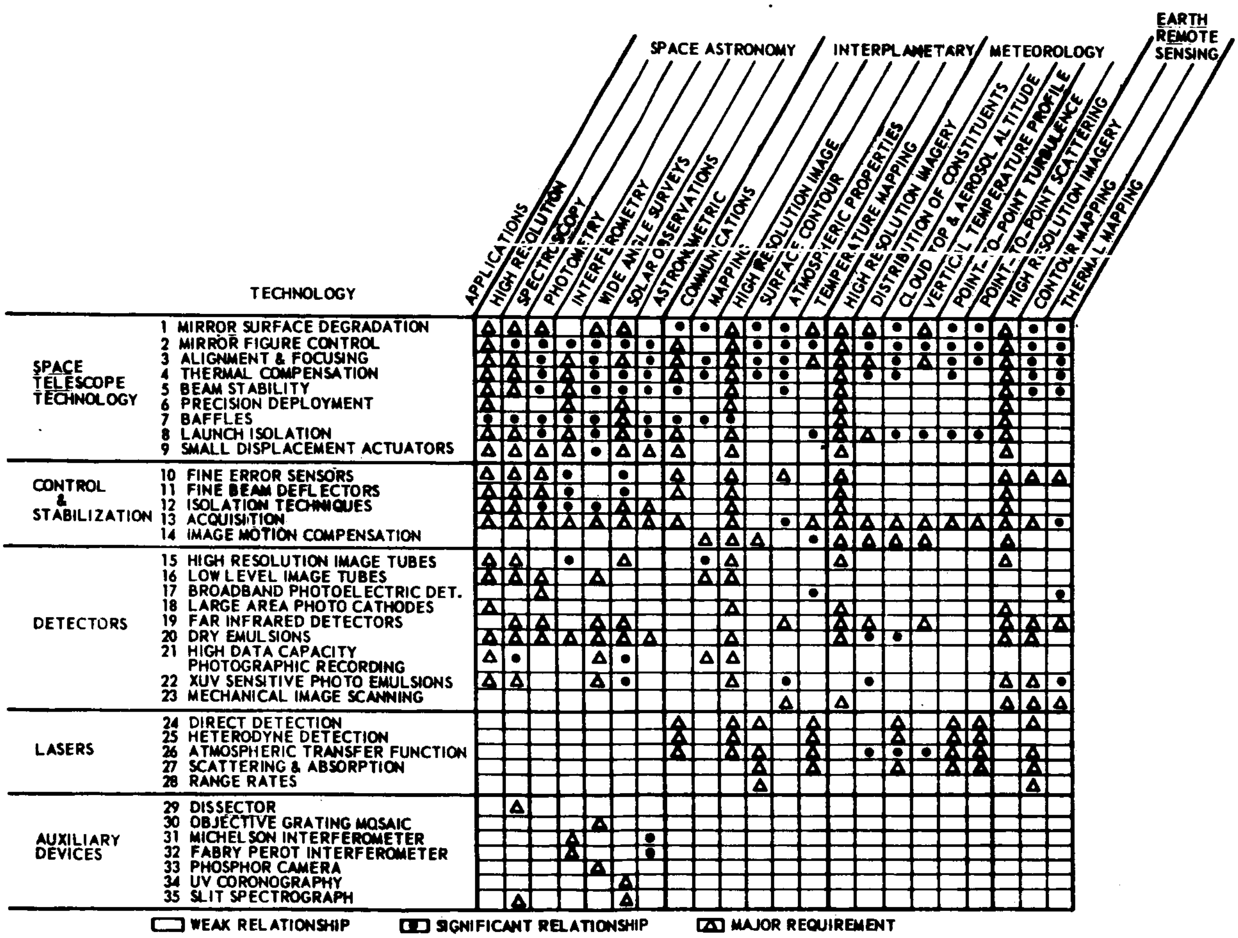


Figure II-1. Commonality of Technology Needs

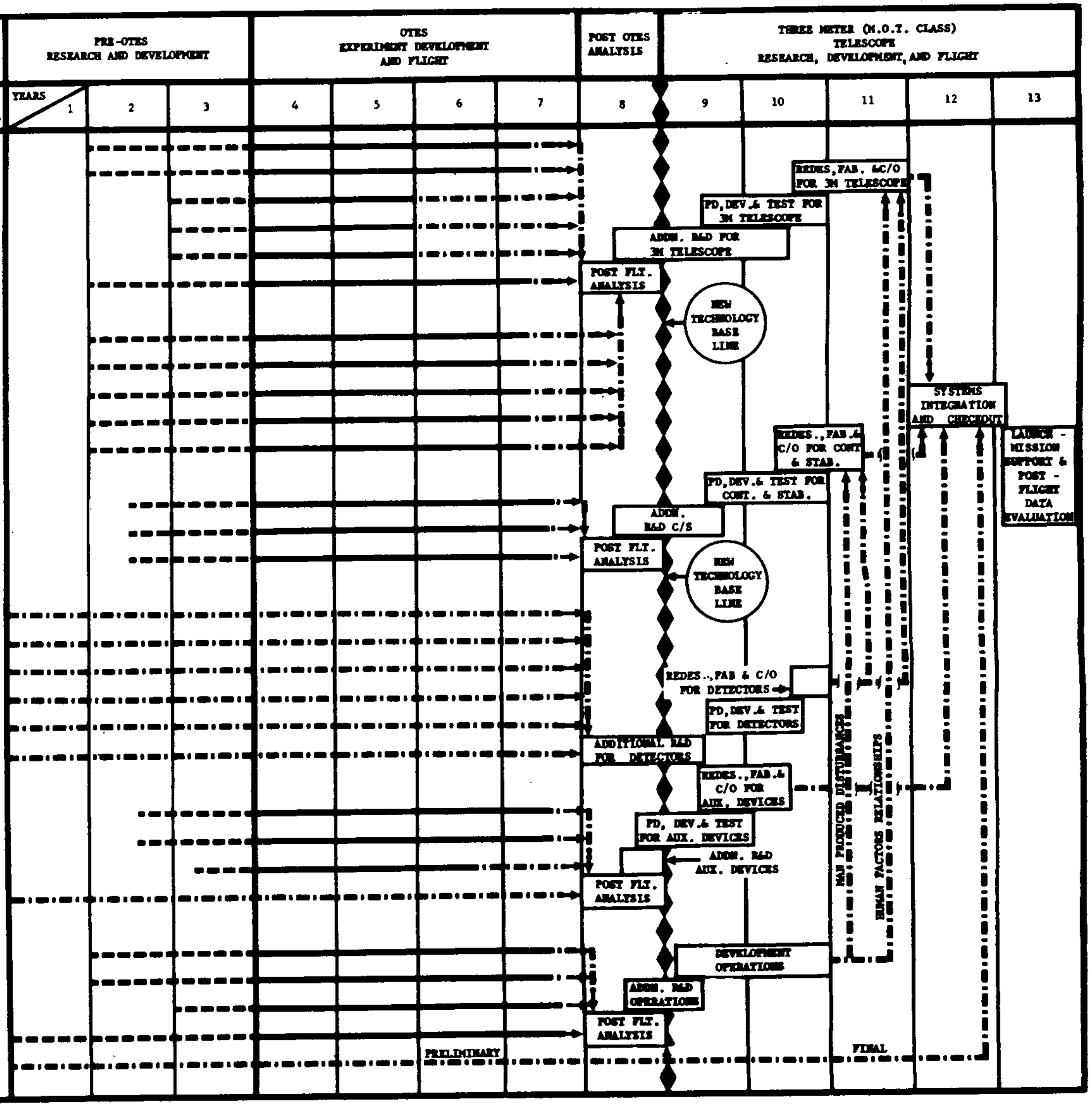
III. MAJOR OBJECTIVES DEVELOPMENT PLAN

One purpose of the OTAES study is to provide NASA with the comprehensive plan for the fulfillment of optical-related space science objectives. As a guide, the OTAES technology development plan used two broad NASA goals: a 3-meter manned orbiting telescope, and an interplanetary optical communications system. Most of the optical technology needs of the objectives, detailed in the first part of the OTAES study, are satisfied by the achievement of these two goals.

A summary development plan was laid out for these two goals. Figures III-1 and III-2 are the plans for the manned orbiting telescope and interplanetary optical communication system, respectively. Specific OTAES experiments as well as prerequisite ground-based testing to support these experiments appear in this schedule plan. Ground-based testing not related to the OTAES experiments is identified by indicating specific technological areas in which such testing will be necessary. These tests, however, have not been time-phased.

It is evident by inspecting these plans that the OTAES experiments, once justified, comprise a necessary step in the attainment of these planned goals. The technology advancements required to attain the long range goals are of such magnitude and complexity that a technology quantum jump approach does not appear feasible, and that space experiments are a logical step to ensure continuous technology advancement in all disciplines. Furthermore, the interdependence of the experiment data, as evidenced by the relationship of each experiment to different technology areas, indicates the need for simultaneous experiment performance in order to fully use the resulting data. This fact indicates that although the experiments can be designed to be flown singly and independently, much more could be gained by launching them in groups on a single vehicle or in closely timed launches.

TECHNOLOGY AREAS	RELATED EXPERIMENTS AND GROUND DEVELOPMENT: OTES EXPERIMENTS	OTES RELATED GROUND DEVELOPMENT	OTHER GROUND DEVELOPMENT
I. OPTICAL SUB-SYSTEM			
A. MATERIALS	10,11,15.	G	REQUIRED
B. MIRROR FIGURE CONTROL	10,11,15	A,M	NOT REQD.
C. CONTAMINATION		G	REQUIRED
D. SURFACE DEGRADATION		G	NOT REQD.
E. MIRROR COATING		G	REQUIRED
F. THIN MIRROR	10,15	G	NOT REQD.
II. TELESCOPE STRUCTURE AND MECHANISMS			
A. PASSIVE THERMAL CONTROL	10,11,15	A,M,N	REQUIRED
B. SMALL DISPLACEMENT ACTUATORS	10,12,14,15	A,J,M,N	REQUIRED
C. ALIGNMENT SENSORS	10,11,15	A,J,M,N	REQUIRED
D. FOCUS SENSORS	10,11,15	A,J,M,N	REQUIRED
E. REMOTE ALIGNMENT PROCEDURES	10,11,15	A,J,M,N	REQUIRED
III. CONTROL/STABILIZATION			
A. TRACKING AND STABILIZATION	12,13		REQUIRED
B. ISOLATION AND GIMBALLING	12,13		REQUIRED
C. ACQUISITION	12	H	REQUIRED
IV. DETECTION AND CONDITIONING			
A. HIGH RESOLUTION DETECTORS		C,P	REQUIRED
B. DETECTORS SENSITIVE TO UV ONLY			REQUIRED
C. BROAD BAND PHOTO ELECTRIC DETECTORS		K	REQUIRED
D. HIGH DATA MAGNETIC TAPE STORAGE			REQUIRED
E. LOW LEVEL PHOTO ELECTRIC TUBE		C,K	REQUIRED
F. NEW DEVELOPMENT EMULSION		C	REQUIRED
V. AUXILIARY DEVICES			
A. VARIABLE DISPERSION SPECTROGRAPHS	12,13	F,J	REQUIRED
B. UV SPECTROGRAPH	12,13	F,J	REQUIRED
C. INTERFERENCE SPECTROMETERS	14		REQUIRED
D. BAFFLE SYSTEMS		E	REQUIRED
VI. OPERATIONS			
A. ERECTION AND CHANGE-OVER PROCEDURES	10,11,14,15	A	REQUIRED
B. LOGISTICS	10,11,14,15	C,E,G,N,	REQUIRED
C. OPERATING MODES	13	S	REQUIRED
D. LAUNCH ENVIRONMENT	ALL		REQUIRED
E. OBSERVATION PROGRAM AND PLAN	NONE	NONE	REQUIRED



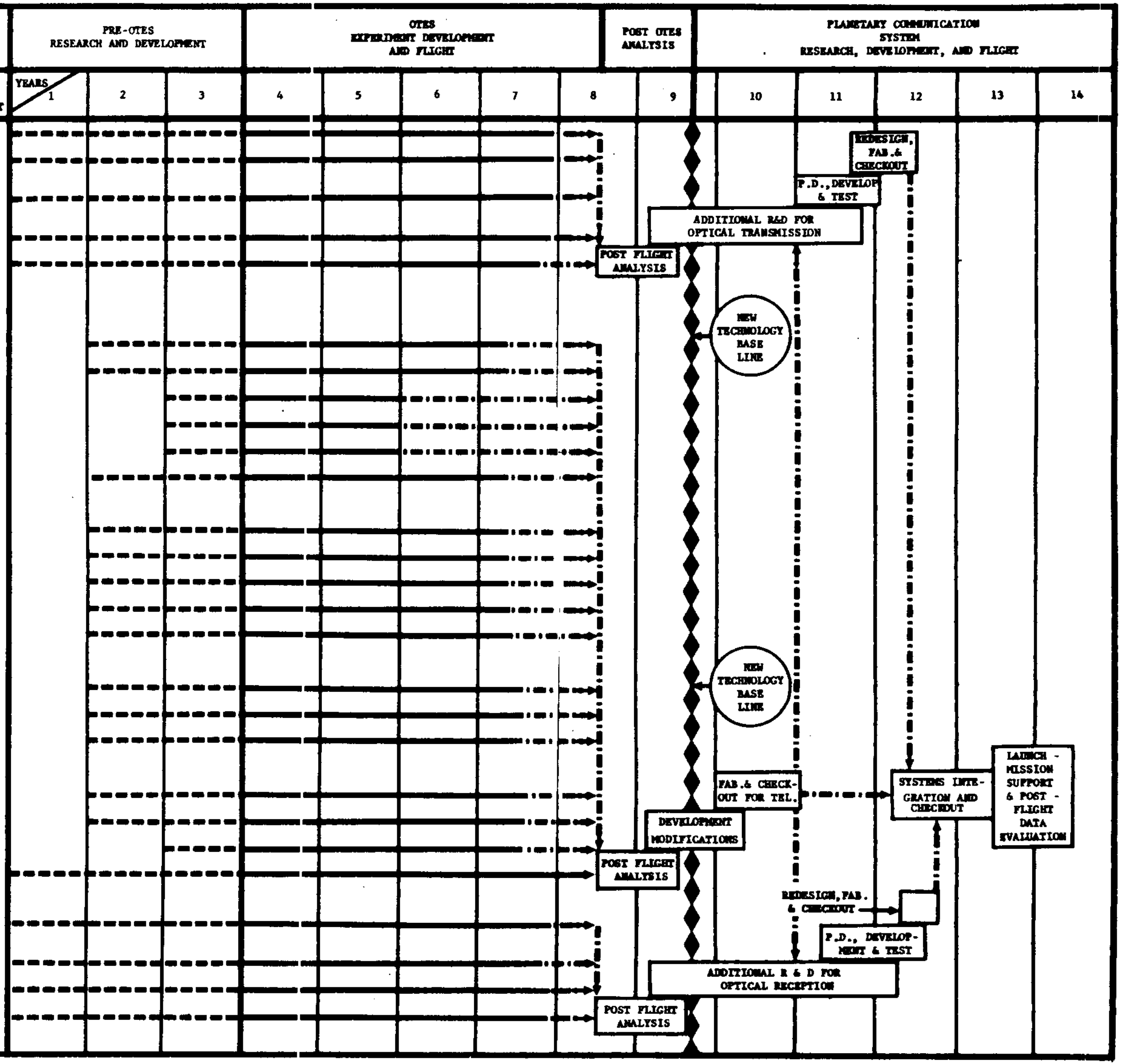
NOTES: 1. THIS FIGURE IDENTIFIES BUT DOES NOT SCHEDULE OTHER NEEDED GROUND DEVELOPMENT NOT SPECIFICALLY IN SUPPORT OF SPACE EXPERIMENTS.

KEY

- ▬▬▬ OTES EXPERIMENT DEVELOPMENT & FLIGHT
- ▬ ▬ ▬ PRE-OTES RESEARCH & DEVELOPMENT
- ▬·▬·▬ GROUND DEVELOPMENT & DELAY TIME

Figure III-1. Long Range Astronomical Technology Development Milestones

TECHNOLOGY AREAS	RELATED EXPERIMENTS AND GROUND DEVELOPMENT: OTES EXPERIMENTS	OTES RELATED GROUND DEVELOPMENT	OTHER GROUND DEVELOPMENT
I. OPTICAL TRANSMISSION			
A. PATH CHARACTERISTICS AND LINK DEGRADATION	1,2,3,4,5,8,9	B	REQUIRED
B. MEANS OF TRANSMISSION	1,2,3,4,5,6,7 8,9	B	REQUIRED
C. SPACE QUALIFIED SUPPORTING COMPONENTS	1,2,3,4,5,6,7 8,9		REQUIRED
D. OPTIMAL TRANSMITTING FREQUENCIES	1,2,3,4,8,9		REQUIRED
E. INFORMATION TRANSMISSION RATE	1,2,3,4		REQUIRED
II. SUPPORTING TELESCOPE TECHNOLOGY			
A. OPTICAL SUB-SYSTEMS			
1. MATERIALS	10,11,15	G	REQUIRED
2. MIRROR FIGURE CONTROL	10,11,15	A,M	NOT REQD.
3. CONTAMINATION		G	REQUIRED
4. SURFACE DEGRADATION		G	NOT REQD.
5. MIRROR COATING		G	REQUIRED
6. THIN MIRROR EVALUATION	10,15	G	NOT REQD.
B. TELESCOPE STRUCTURE & MECHANISMS			
1. PASSIVE THERMAL CONTROL	10,11,15	A,M,N	REQUIRED
2. SMALL DISPLACEMENT ACTUATORS	10,12,14,15	A,J,M,N	REQUIRED
3. ALIGNMENT SENSORS	10,11,15	A,J,M,N	REQUIRED
4. FOCUS SENSORS	10,11,15	A,J,M,N	REQUIRED
5. REMOTE ALIGNMENT PROCEDURES	10,11,15	A,J,M,N	REQUIRED
C. CONTROL AND STABILIZATION			
1. POINTING AND TRACKING	5,6,7	B,E,H	REQUIRED
2. POINT AHEAD	6		REQUIRED
3. ACQUISITION	5,7	B,H	REQUIRED
D. OPERATIONS			
1. ERECTION AND CHANGE-OVER PROCEDURES	10,11,14,15	A	REQUIRED
2. LOGISTICS	10,11,14,15	C,E,G,N	REQUIRED
3. OPERATING MODES	13	S	REQUIRED
4. LAUNCH ENVIRONMENT	ALL		REQUIRED
III. OPTICAL RECEPTION			
A. TYPE OF RECEIVER	1,2,3,4,5,6, 7,8,9	K,R	REQUIRED
B. MEANS OF DETECTION	1,2,3,4,6,9	K,R	REQUIRED
C. OPTIMAL RECEIVING FREQUENCY	1,2,3,4,8,9	K	REQUIRED
D. SIGNAL PROCESSING	1,2,3,4,6,7 8,9		REQUIRED



NOTES: 1. THIS FIGURE IDENTIFIES BUT DOES NOT SCHEDULE OTHER NEEDED GROUND DEVELOPMENT NOT SPECIFICALLY IN SUPPORT OF SPACE EXPERIMENTS.

KEY

- OTES EXPERIMENT DEVELOPMENT AND FLIGHT
- PRE-OTES RESEARCH AND DEVELOPMENT
- GROUND EXPERIMENTS AND DELAY TIME

Figure III-2. Long Range Optical Propagation Technology Development Milestones

IV. RECOMMENDED OTAES EXPERIMENTS

While generating the technology development plan, it was found that not all of the technology requirements can be satisfied with a ground-based development program. This led to the definition of a space experiment program to complete the technology development. Each experiment was defined and developed by specialists in the particular technological area. Each specialist was asked to justify his experiment on the basis of its contribution to the scientific objectives, need for space testing, and feasibility. The experiments were designed to the level of conceptual detail required to provide a basis for experiment integration.

A schedule was developed for each recommended OTAES experiment. These schedules were classified into two parts: the research and development activity which is necessary before entering the preliminary design phase, and the activity ranging from preliminary design through fabrication.

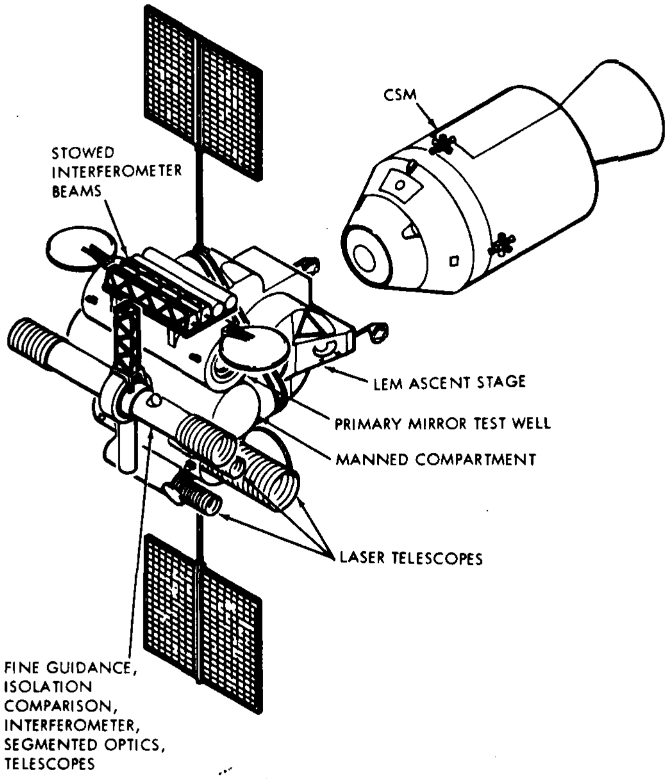
Specific research and development milestones were identified. These are described under the headings of OTAES Prerequisite Technology Digests for each specific experiment.

Each experiment development schedule lists the major assemblies/subsystems that are experiment peculiar. All of the telescope associated experiments list the respective telescope(s) even though the specific experiment may not be the prime user of the telescope(s). Other support or interdependent subsystems are treated in the prime experiment to avoid redundancy where possible. Where it is possible to do so, references indicating specific support required appear in lieu of a relisting of the major assemblies/subsystems.

The rest of this section contains a brief summary of each experiment, the experiment schedule, and the prerequisite technology digest.

EXPERIMENTS

1. Optical Heterodyne Detection on Earth.
2. Optical Heterodyne Detection on the Spacecraft.
3. Direct Detection Space-to-Ground.
4. Communication with 10 Megahertz Bandwidth.
5. Precision Tracking of a Ground Beacon.
6. Point Ahead and Space-to-Ground-to-Space Loop Closure.
7. Transfer Tracking from One Ground Station to Another.
8. Phase Correlation Measurements.
9. Pulse Distortion Measurements.
10. Primary Mirror Figure Test and Correction.
11. Thin Mirror Nesting Principle and Erection and Alignment of Large Optics in Space.
12. Fine Guidance.
13. Comparison of Isolation Techniques.
14. Interferometer Systems.
15. Segmented Optics.



OTAES Spacecraft No. 1

1. Optical Heterodyne Detection on Earth Experiment

The atmosphere has been studied for centuries from earthbound observatories using the non-coherent light from stars. Rockets and satellites now permit remote measurements of the Earth and its atmosphere. To make optimum use of remotely sensed data, more must be known about the physics of the atmosphere and the effects of the atmosphere on optical signals passing through it. As a tool to advance our knowledge in these areas, the laser possesses two highly useful properties: spatial and temporal coherence. A laser transmitter can emit an extremely narrow, intense beam of monochromatic light. Furthermore, since it operates at frequencies sensitive to atmospheric absorption, scattering, and variations in the index of refraction, the laser is a most promising instrument for obtaining a better understanding of the turbulent structure of the atmosphere.

To study the physics of the atmosphere using a spaceborne light source is to study the character of a space-ground transmission path. The establishment of such a path is tantamount to establishing an optical communication link. Indeed, the most promising operational application for lasers is wide-band communication over extremely long distances. By providing sufficient data transfer rates, the laser may make exploration of the remote planets feasible - and may thus assist in setting the post-Apollo national goals in space.

Tests over horizontal paths on Earth and from high level balloons are prerequisite to the proposed spaceborne experiment, but in themselves would be inadequate. Aircraft tests are not possible because the turbulence local to a lifting body would mask the effect to be measured and because of the aircraft vibration environment. Balloon testing eliminates the upper atmosphere from the transmission medium – an element which is critical to both the atmospheric physicist's purposes, in which upper air effects and turbulences constitute a primary class of unknowns, and to the communication theorist who seeks to reduce the total transmission medium to verify or refine the postulates in his simulations. Simulation of the space-to-Earth medium (and rigorous correlation of earth-based test results) cannot be fully credible until a well planned space-to-Earth experiment is performed.

This experiment consists of transmitting two laser wavelengths (0.6328μ and 10.6μ) both separately and simultaneously and receiving them on Earth. Within the experiment, provision is made for combining various signal forms, coding, and modulation methods for test under atmospheric constraints. Such tests require a spaceborne transmitter. From the communication viewpoint, it is necessary to determine the capacity of the transmission medium. Statistical data must be gathered over a period of many hours and repeated for many days. Signal distortion measurements must be made through the entire sensible atmosphere, and results must be correlated with observable meteorological paramters. The atmospheric physics content of this experiment is predicted on near-zenith elevation angles.

Collectively, the space-to-ground communication experiments provide a comparison of the two fundamental communication techniques: direct detection and heterodyne detection.

PROJECT: OTAES PH I EXTENSION

LEGEND: OPTICAL HETERODYNE DETECTION ON EARTH
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

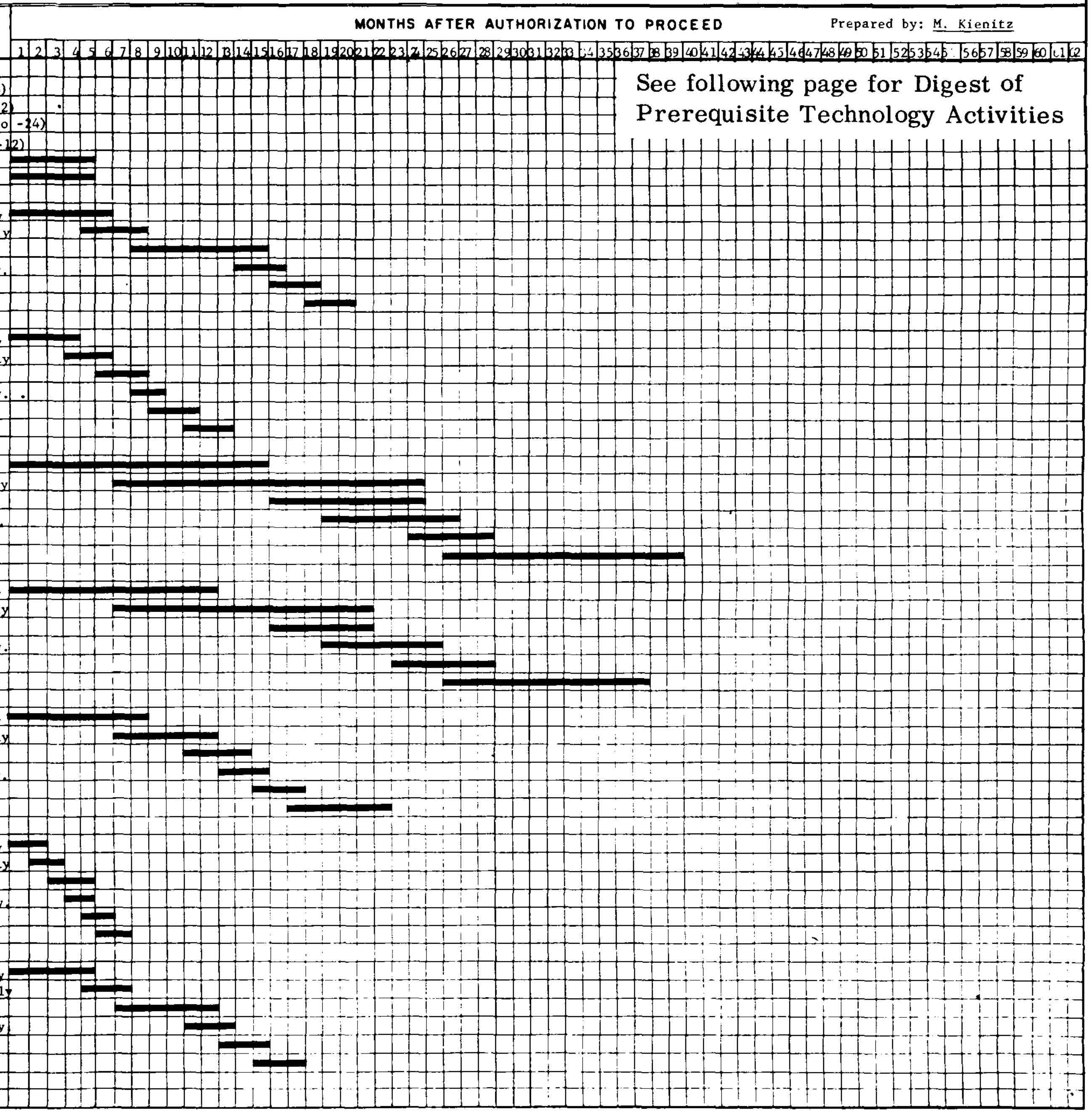
Figure IV-1

Detail Schedule E-1
Sheet 1 of 2 Sheets
Date: 2 August 1966

Prepared by: M. Kienitz

See following page for Digest of Prerequisite Technology Activities

ADVANCED DEVELOPMENT EFFORT		TITLE
RESEARCH & DEVELOPMENT SUMMARY		
Tas #1		IR Detector Dev. (-36 to -6)
Task #2		Video Modulator Dev. (-36 to -12)
Task #3		HeNe & N_2CO_2 Laser Dev. (-36 to -24)
Task #4		Ground/Ground Meas. (-24 to -12)
Task #5		Pulse Distort. Invest. (-24
Task #6		Ground/Space Meas. (-12
ITEM No	ASSEMBLY NAME	Major Assemblies/Sub-Systems
1	Single Frequency Laser Transmitters	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
2	Electro-Optic Modulator	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
3	Transmitting Telescope 1.0M	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
4	Transmitting Telescope 0.3M	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
5	Tracking Telescope (Ground)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
6	Optical Filters	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
7	Duplex Heterodyne Receivers	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy
		Final Design of Assembly
		Manufacture of Assembly



PROJECT: OTAES PH I EXTENSION

LEGEND: OPTICAL HETERODYNE DETECTION ON EARTH
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-1

Detail Schedule E-1
Sheet 2 of 2 Sheets
Date: 2 August 1966
Prepared by: M. Kienitz

MONTHS AFTER AUTHORIZATION TO PROCEED (1–62)

ITEM No.	ASSEMBLY NAME	TITLE
		Major Assemblies/Sub-Systems (Cont'd)
8	Dichroic Mirrors	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly

DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 36 months

Research and Development

a. Video modulators development for use at 10.6 microns wavelength (24 months).

b. Infrared photo detectors development having high quantum efficiency at 10.6 microns and having a frequency response extending to at least 10 megahertz (30 months). (Developments in tunable optical parametric oscillators may make it possible to overcome the doppler shift encountered on interplanetary missions if a good video bandwidth detector is available at 10.6 microns.)
(1) Analysis of semiconductor materials or techniques capable of adequate frequency response.
(2) Unit design and packaging studies for inclusion of IR detectors, dewars, high-frequency coupling structures and cooled optical filters.

c. Stable 10.6-micron laser development with emphasis on ruggedization (24 months, now in process).
(1) Study to devise rugged structures that are resistant to environmental factors.
(2) Servo systems analysis for compensation of unavoidable changes.

d. Laser mode control and stabilization techniques development (24 months, now in process).

e. Space-qualified helium-neon and N_2-CO_2 lasers development (12 months).
(1) Structural design analysis for gas lasers capable of remote alignment and tuning.
(2) Studies to restrict heat radiation for the laser package.
(3) Develop and test gas discharge tubes to withstand environmental factors and provide long-life, reliable performance.
(4) Investigate both dc cold cathode and rf pumping systems.
(5) Compact packaging and miniaturization studies.
(6) Conduct shock and vibration tests on completed designs.

f. Ground-to-ground measurements program of atmospheric coherence diameters at 10.6 microns wavelength and pulse distortion measurement tests at 0.6328 microns where broad-band photo detectors are available (12 months).
(1) Establish propagation test range(s) for one way tests (no mirrors or reflectors) with a capability of measuring a variety of test paths and a path length of at least 2 miles.
(2) Determine the dependence of effective receiver coherence diameter at 10.6 microns on weather conditions, site locations, etc.
(3) Determine the upper limit on bandwidth of signals that can be propagated at 0.6328 microns through pulse distortion measurements of the output of an AM-locked multimode laser.
(4) Conduct simultaneous tests utilizing 10.6 micron CW and 0.6328 micron fast pulse systems for more accurate comparative data.

g. Ground-to-ground tests of a complete optical communication system.
(1) Evaluate the communication system capabilities for various modulation and detection schemes under a variety of atmospheric conditions.
(2) Collect and analyze data on fading and fading rates for comparison with theory, for the design of an electronic system to simulate the effects of the atmosphere in the laboratory, and for comparison with data to be obtained on high angle slant paths.
(3) Evaluate performance and reliability of the 10.6 micron receiver system.

h. Laser stabilization development of ruggedized video bandwidth detectors for the visible spectrum video bandwidth modulators for the 10 micron band (12 months).

i. Piggyback space-to-ground propagation experiment design and fabrication emphasizing pulse distortion measurements at 0.6328 microns and coherent aperture measurements at 10.6 microns wavelength (30 months).
(1) Detail design of an operating laser system or systems that will make atmospheric diagnostic measurements. The systems will be configured to an AAP pallet package, allowing some preliminary testing of space hardware, of atmospheric properties, and of pointing and tracking system capabilities.
(2) Laser transmitter(s) accuracy requirements analysis for illumination of a ground receiving station.
(3) High-angle, space-to-ground path measurements of these signal properties that have been investigated on ground-to-ground paths.
(4) Fabrication of subsystems and components for a piggyback system.

j. Propagation tests at several laser wavelengths over high-angle atmospheric paths, using high-altitude balloons, platforms, and satellites having usable corner reflectors at 10.6 microns wavelength.
(1) Perform upper atmosphere-to-ground propagation measurements. Wavelengths of 0.6328 and 10.6 microns plus other new laser wavelengths will be used.
(2) Long path measurements of those parameters that have been measured in ground-to-ground tests. Measurement of atmospheric coherence diameters at 10.6 microns and of fast pulse distortion at 0.6328 microns will be compared under these conditions.

EFFORT	FINAL ASSEMBLY AND C/O
TASK "A"	Final Assembly of Experiment Primary Flight Article
TASK "B"	Functional Check-Out of Exper. Primary Flight Article
TASK "C"	Final Assembly of Experiment Backup Flight Article
TASK "D"	Functional Check-Out of Experiment Backup Article

2. Optical Heterodyne Detection on the Spacecraft Experiment

The previous discussion on the need for earth-based detection is applicable here also. The two experiments require different operational procedures and incorporate different designs, but derive their justification from the same source.

This experiment consists of transmitting two laser wavelengths (0.488μ and 0.6328μ) from the Earth and detecting them on the spacecraft. Both heterodyne and direct detection will be used. Quantities to be measured in space are receiver signal power, heterodyne signal power, and fluctuations in both polarization and phase. The results will be compared with those obtained from the downlink. An important point is that this and the previous experiment should be performed simultaneously.

PROJECT: OTAES PH I EXTENSION

LEGEND: OPTICAL HETERODYNE DETECTION ON THE SPACECRAFT
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-2

Detail Schedule E-2
Sheet 1 of 2
Date: 2 August 1966
Prepared by: M. Kientz

MONTHS AFTER AUTHORIZATION TO PROCEED (1–62)

ADVANCED DEVELOPMENT EFFORT		TITLE
RESEARCH & DEVELOPMENT SUMMARY		
Task #1		Laser Local Oscillator Dev. (-36 to -12)
Task #2		Laser Transmitter Dev. (-36 to -12)
Task #3		Ground/Space Meas. (-24 to -1)
Task #4		Ground/Ground Meas. (-12 to -1)
Task #5		Component Research (-12 to -1)
ITEM No	ASSEMBLY NAME	Major Assemblies/Sub-Systems
1	Super-Mode Laser Transmitter	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy
		Final Design of Assembly
		Manufacture of Assembly
2	Electro-Optic Modular	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy
		Final Design of Assembly
		Manufacture of Assembly
3	Transmitting Telescope 10 CM	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy
		Final Design of Assembly
		Manufacture of Assembly
4	Tracking Telescope 1.0M (Space)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
5	Tracking Telescope 0.3M	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
6	Optical Filter	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
7	Duplex Heterodyne Receiver	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly

DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 36 months

Research and Development

a. Low-power stable, single-frequency, laser local oscillators development, with emphasis on design for space qualification. (Developments in tunable optical parametric oscillators may make it possible to overcome the doppler snift encountered on inter-planetary missions if a good video bandwidtn detector is available.) (24 months).

b. Stable transmitter laser development with emphasis on ruggedization (12 months).

c. Laser mode control and stabilization tecnniques development (24 months, now in process.)

d. Rudimentary satellite piggyback transmission experiment development.

e. Ground-to-ground tests of a complete optical communication system, transmitting several wavelengths simultaneously (9-12 months). See optical heterodyne detection on Earth experiment.

f. Propagation tests at several laser wavelengths over high-angle atmospheric paths, using either high-altitude balloons or synchronous satellites. See optical heterodyne detection on Earth experiment.

g. Space-simulation testing of lasers, modulators, and detectors (6-9 months).

PROJECT: OTAES PH I EXTENSION

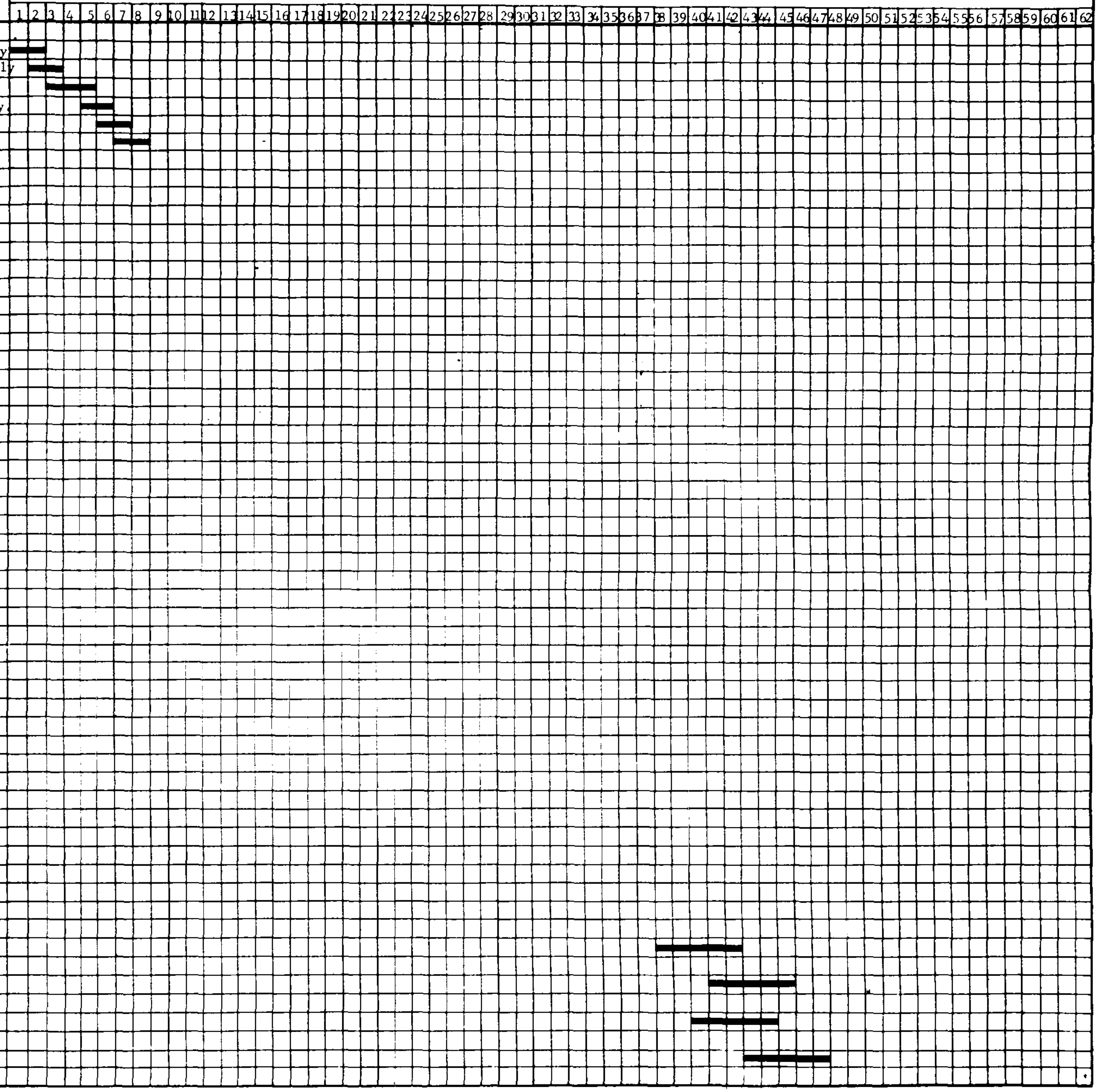
LEGEND: OPTICAL HETERODYNE DETECTION ON THE SPACECRAFT
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-2

Detail Schedule E-2
Sheet 2 of 2
Date: 2 August 1966
Prepared by: M. Kientz

ITEM No.	ASSEMBLY NAME	TITLE
8	Dichroic Mirror	Major Assemblies/Sub-Systems
		Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
EFFORT		FINAL ASSEMBLY AND C/O
TASK "A"		Final Assembly of Experiment Primary Flight Article
TASK "B"		Functional Check-Out of Exper. Primary Flight Article
TASK "C"		Final Assembly of Experiment Backup Flight Article
TASK "D"		Functional Check-Out of Exp. Backup Article

MONTHS AFTER AUTHORIZATION TO PROCEED



3. Direct Detection Space to Ground Experiment

One potential application for lasers is communication at very long ranges. The preceding experiments have treated the optical heterodyne technique. Direct detection also applies as an alternative communication form which has planetary distance potential.

There are three salient advantages to the direct detection concept: system simplicity, lenient pointing tolerances, and an advanced state of ground-based development. In fact, direct detection system tests can be implemented on OTAES by defocusing the telescope, in the same fashion that is prerequisite to the precision tracking experiment, and by using the optical heterodyne transmitter. Thus, at the expense of a few logic elements in its test program sequencer, the OTAES spacecraft can be adapted for the direct detection experiment. The one element of an optical direct detection system which remains to be developed is the large, earth-based optical collector. For a meaningful comparison (i.e, in a planetary communication context) with alternative techniques, this aperture should be 8 meters in diameter. In this size, solar furnace technology and conventional RF antenna tracking techniques apply.

The reasons for performing this experiment in space are the same as for the preceding laser experiments.

The experiment is the same as the heterodyne detection on earth experiment, except that direct detection is used. The specific objective is to evaluate the performance of a wide-band, space-ground laser communications technique that uses state-of-the-art components, but does not require diffraction-limited optics, extreme pointing accuracy, or excessive power consumption.

Since spacecraft tolerances and requirements are relaxed in comparison to the heterodyne detection experiment, there is a greater probability of experiment success.

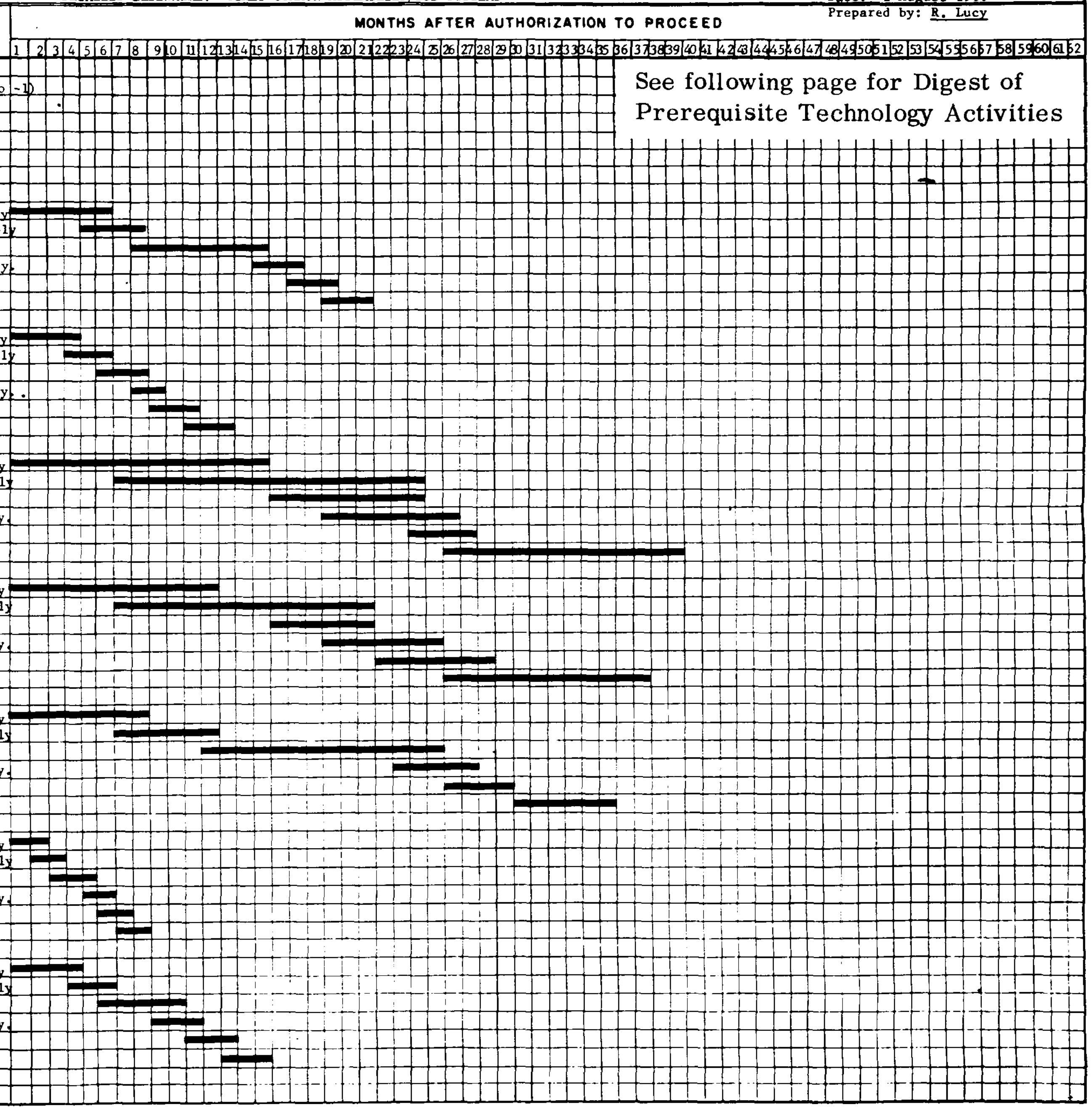
PROJECT: OTAES PH I EXTENSION

LEGEND: DIRECT DETECTION - SPACE TO GROUND
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-3

Detail Schedule E-4
Sheet 1 of 2
Date: 2 August 1966
Prepared by: R. Lucy

ADVANCED DEVELOPMENT EFFORT		TITLE
RESEARCH & DEVELOPMENT SUMMARY		
Task #1		E/O Modulator Research (-24 to -1)
ITEM No	ASSEMBLY NAME	Major Assemblies/Sub-Systems
1	Laser Transmitters (Space)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
2	Electro-Optical Modulator	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
3	Transmitting Telescope 1.0M	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
4	Transmitting Telescope 0.3M	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
5	Optical Collector 10.0M	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
6	Optical Filter	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
7	Direct Detection Receiver	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly



PROJECT: OTAES PH I EXTENSION	LEGEND: DIRECT DETECTION - SPACE TO GROUND (CONTINUED) LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS	Figure IV-3	Detail Schedule E-4 Sheet 2 of 2 Date: 2 August 1966 Prepared by: R. Lucy

MONTHS AFTER AUTHORIZATION TO PROCEED

ITEM No.	ASSEMBLY NAME	TITLE
8	Dichroic Mirror	Major Assemblies/Sub-Systems
		Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy
		Final Design of Assembly
		Manufacture of Assembly

EFFORT	FINAL ASSEMBLY AND C/O
TASK "A"	Final Assembly of Experiment Primary Flight Article
TASK "B"	Functional Check-Out of Exp. Primary Flight Article
TASK "C"	Final Assembly of Experiment Backup Flight Article
TASK "D"	Functional Check-Out of Exper. Backup Flight Article

DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 24 months

Research and Development

a. Space Optical Modulation System
  (1) Electro-optic modulator and driver model studies and development (24 months).
    (a) Development of two space-qualified service test models of a 0.6328 micron modulator and solid state driver with 100 megahertz video bandwidth developing 100 per cent modulation with 10 watts signal power.
    (b) Trade-off analyses of several electro-optic crystal materials including crystal optical damageability analysis and studies of optical surface quality characteristics and their retention.
    (c) Studies of the transmittance characteristics of the optical components in the modulator as well as optimizing the anti-reflection coating techniques for internal heating minimization.
    (d) Analysis of methods to minimize the modulator thermal birefringence.
    (e) Review and summarization for various communication modulation formats (FM, FM-subcarrier, pulsed intensity modulation, pulsed polarization modulation, etc.) for impact on modulator design and crystal characteristics.
    (f) Studies of launch survival and alignment retention in the space environment to minimize deflection and decollimation of the output beam.
    (g) Measurement of the distortion of the emergent beam across its diameter.
  (2) Prototype model development (15 months).
    (a) Design laboratory modulators and associated solid state drive amplifiers to operate at 10.6 microns, and video bandwidth of 100 megahertz.
    (b) Trade-off analyses of electro-optic material characteristics (conductivity, thermally induced birefringence, transmittance, optical surface qualities and coatings and their retention) for applicability to planetary communication.
  (3) Final model development (15 months).

b. Ground-based Tracking Receiver
  (1) Prototype development of 23-meter diameter model with a 0.5 milliradian maximum field of view (24 months.)
    (a) Design, construction and installation of the optical collector, secondary optics, narrow-band interference filters, optical demodulators, photodetectors, and associated electronics.
    (b) Analysis of various means to acquire the remote laser transmitter, provide the tracking error input to the servo controlled mount, and provide an auxiliary pointing and tracking data input for radar or computer program control of the system.
  (2) Horizontal path ground tests and air-to-ground tests to develop design parameters for full-scale model.
  (3) Final 8 to 10-meter diameter model development (24 months).
    (a) Design and construction of 8-10 meter direct detection receiver based on prototype tests and experience.
    (b) Installation of receiver at predetermined ground station site.
  (4) Data recording, display, and reduction system analysis and development (24 months).
    (a) Requirements, analysis, design, and construction of display and recording facilities.
    (b) Requirements analysis, design, and construction of real time data processing equipment for signal fading information collection in experiment control.
    (c) Data system integration with other experiment data and control systems.

Remarks: Extensive earth-based testing of the direct detection optical communication concept has already been accomplished over horizontal paths. Recent air-to-ground tracking experiments have been performed using a narrow laser beam pointed at a retroreflector mounted on an aircraft.

4. Communication with 10 Megahertz Bandwidth Experiment

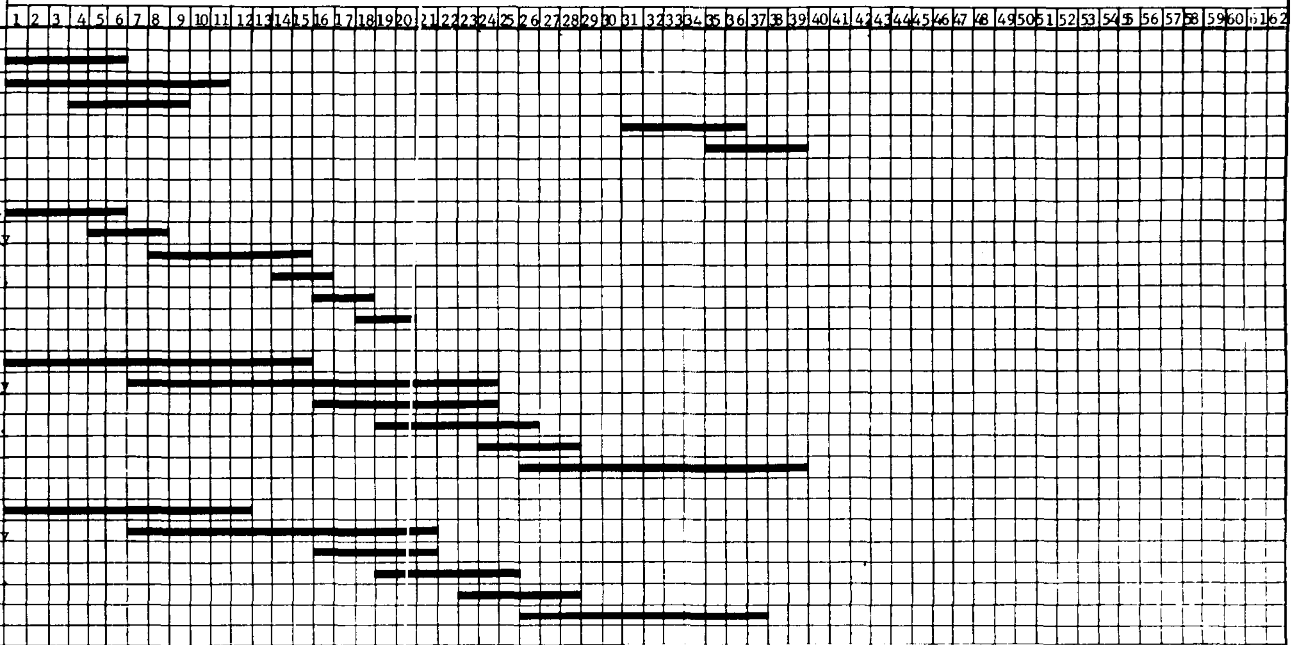
The rapidly increasing data gathering capabilities of deep space probes have made necessary the development of techniques for transmitting data at maximum rates using a minimum of spacecraft power. The rate at which data can be transmitted varies directly as the bandwidth of the communication channel. Optical communication, using wide bandwidth modulation and detection techniques, offers a potential solution for this need. Very narrow beamwidths are obtainable at optical wavelengths using nominal apertures, providing high energy density in the beam for reasonable amounts of transmitted power. The high energy density will support wide bandwidth communication with high signal-to-noise ratio.

Performance of wide bandwidth optical communication systems can be analytically determined by making assumptions about the propagation path and assuming mathematically ideal system components. However, it can be expected that a communication system placed in orbit will depart from this mathematical ideal. Determination of the effect of these departures on systems performance can only be measured by placing them in the orbital environment. Because the atmosphere is neither homogeneous nor isotropic, and because the applicable theory is not developed for the general case, it is necessary that the measurements be made along actual transmission paths through the entire atmosphere. The few measurements made to date have been over relatively short, nearly horizontal paths which cannot be considered representative of an actual space-to-ground transmission path. Present knowledge of the atmosphere does not permit accurate estimates to be extrapolated from measurements made along the horizontal paths. This can only be accomplished from an orbiting satellite. Variations of the atmosphere and its effect on the system bandwidth performance must be measured over a long time period to obtain statistical data.

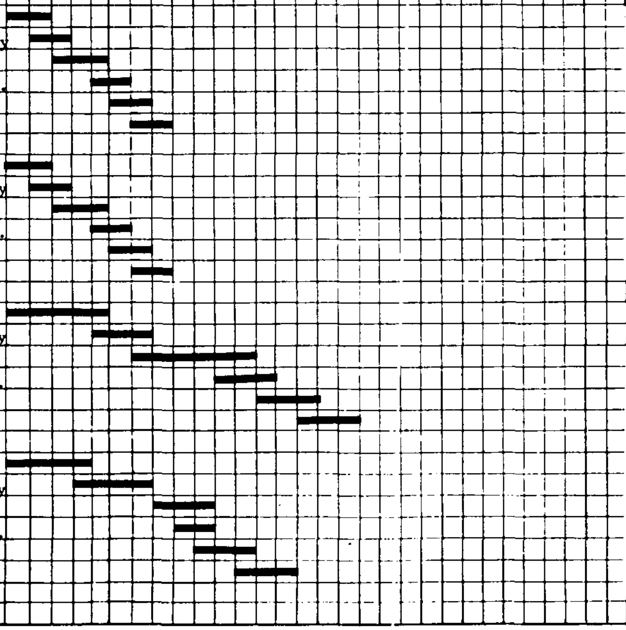
The wideband communication experiments are planned to be operated as an extension of the first three experiments. The first experiment will be the direct detection experiment. When it has been determined that the direct detection experiment on Earth is operating satisfactorily, the modulator will be supplied a wave-band signal from the signal wave. Transmission will be made over extended periods of time to obtain signal characteristics and error rate information as a function of atmosphere characteristics, pointing accuracy, and receiver aperture size.

PROJECT: OTAES PH I EXTENSION	LEGEND:	COMMUNICATION WITH 10 MEGAHERTZ BANDWIDTH LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS	Figure IV-4	Detail Schedule E-3 Sheet 1 of 3 Date: 2 August 1966 Prepared by: N. Gundersen

MONTHS AFTER AUTHORIZATION TO PROCEED



ADVANCED DEVELOPMENT EFFORT		TITLE
RESEARCH & DEVELOPMENT SUMMARY		
Task #1		Modulator Material Studies
Task #2		Theoretical Detector Research
Task #3		Modulator Lab Test
Task #4		Ground Tests
Task #5		Airborne Tests
ITEM No	ASSEMBLY NAME	Major Assemblies/Sub-Systems
1	Laser Transmitters (Space)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy
		Final Design of Assembly
		Manufacture of Assembly
2	Transmitting/Receiving Telescope 1.0M (Space)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
3	Transmitting/Receiving Telescope 0.3M (Space)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
4	Dichroic Mirrors (Space)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
5	Optical Filters (Space)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
6	Duplex Heterodyne Receiver (Space)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
7	Electro-Optic Modulators (Space)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly



DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 36 Months

Research and Development

a. Wideband modulator development for 10.6 micron wavelength at 10 megahertz bandwidth (24 months).
   (1) Material analysis
   (2) 10.6 micron wavelength development

b. Wideband detector development for 10.6 micron wavelength at 10 megahertz bandwidth (36 months).

c. Laser (all-wavelengths) space-qualification through simulation on the ground (24 months).

d. 10.6 micron modulator space-qualification through simulation on the ground (12 months).

e. 10.6 micron detector space-qualification through simulation on the ground (18 months).

f. 10 megahertz systems tests for ground link (9 months).

g. 10 megahertz systems tests, aircraft-to-ground link (12 months).

Remarks: The present state-of-the-art modulators and detectors at 0.488 microns, 0.6328 microns, and 1.06 microns is well beyond 10 megahertz. It is possible that present modulators can be extended for operation at 3.39 microns; however, detectors for 3.39 microns and detectors and modulators for 10.6 microns wavelengths are not capable of 10 megahertz frequency response. Additional advancements must be made in the area of cryogenic cooling for detectors.

PROJECT: OTAES PH I EXTENSION

LEGEND: COMMUNICATION WITH 10 MEGAHERTZ BANDWIDTH
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYS EMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

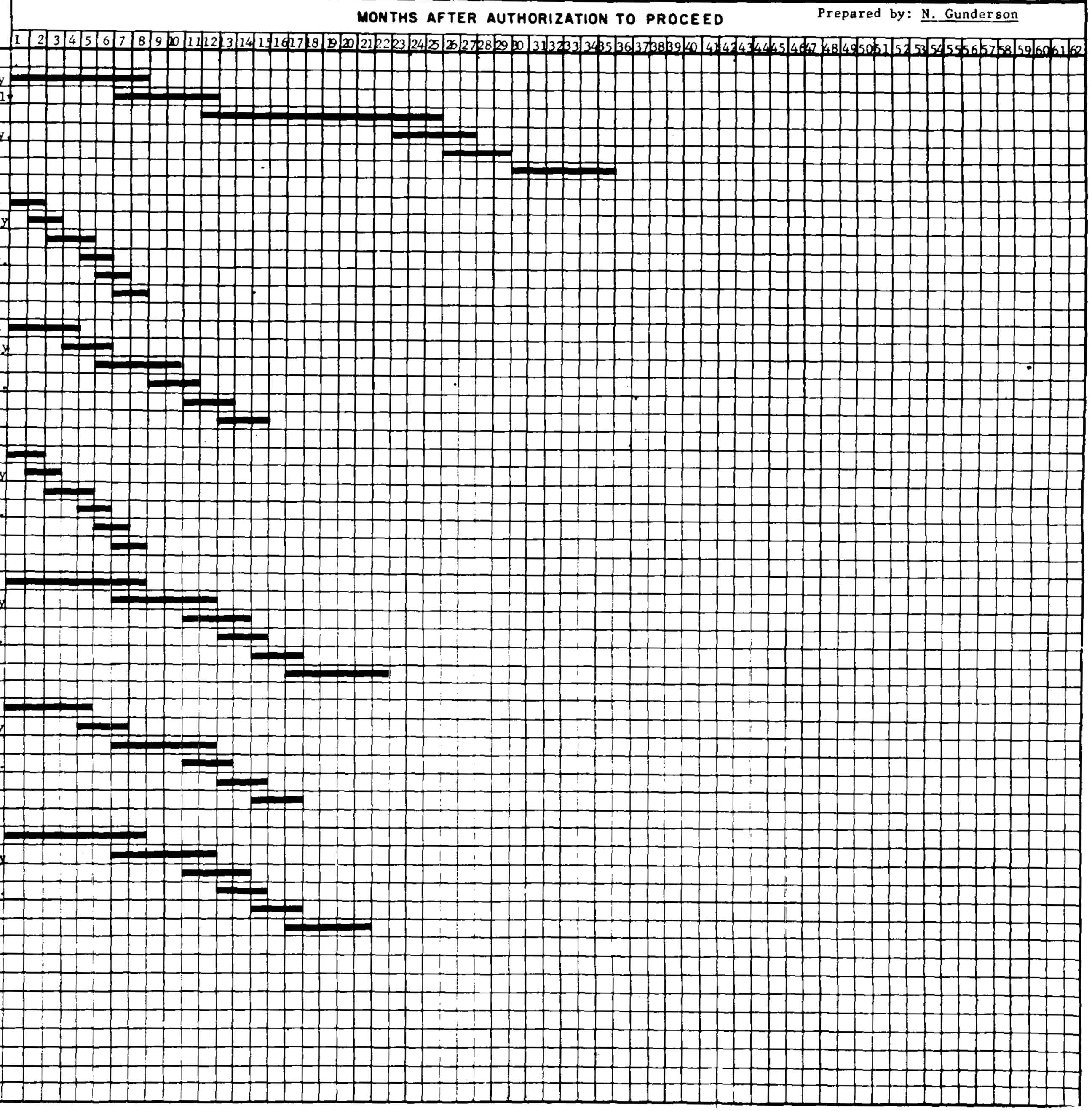
Figure IV-4

Detail Schedule E-3
Sheet 2 of 3
Date: 2 August 1966

Prepared by: N. Gunderson

ITEM No.	ASSEMBLY NAME	TITLE
8	Optical Collector 10.0M (Ground)	Major Assemblies/Sub-Systems
		Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
9	Optical Filters (Ground)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
10	Direct Detection Receiver (Ground)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
11	Dichroic Mirrors (Ground)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
12	Tracking Telescope (Ground)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
13	Duplex Heterodyne Receiver (Ground)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
14	Transmitting Telescope	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
EFFORT		FINAL ASSEMBLY AND C/O
TASK "A"		(See Sheet 3 of 3)
TASK "B"		
TASK "C"		
TASK "D"		

MONTHS AFTER AUTHORIZATION TO PROCEED



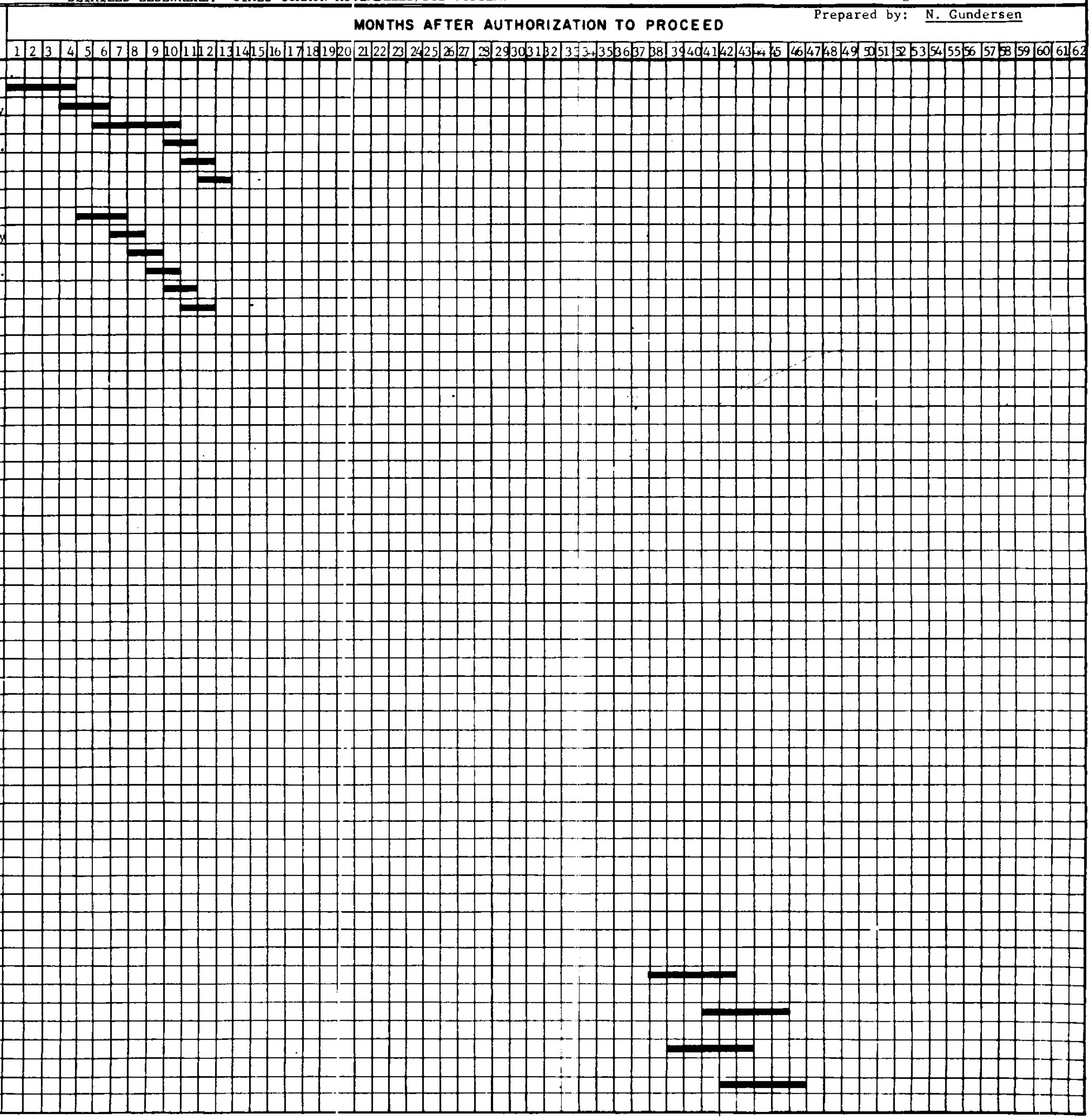
PROJECT: OTAES PH I EXTENSION

LEGEND: COMMUNICATION WITH 10 MEGAHERTZ BANDWIDTH
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-4

Detail Schedule E-3
Sheet 3 of 3
Date: 2 August 1966
Prepared by: N. Gundersen

ITEM No.	ASSEMBLY NAME	TITLE
		Major Assemblies/Sub-Systems
15	Supermode Laser Transmitter (Ground)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
16	Electro-Optic Modulator (Ground)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
EFFORT		FINAL ASSEMBLY AND C/O
TASK "A"		Final Assembly of Experiment Primary Flight Article
TASK "B"		Functional Check-Out of Exp. Primary Flight Article
TASK "C"		Final Assembly of Experiment Backup Flight Article
TASK "D"		Functional Check-Out of Backup Article



5. Precision Tracking of a Ground Beacon Experiment

Two way, wide-bandwidth laser communication links for space application will require that the laser power be concentrated in very narrow beam widths because of power limitations in the spacecraft. To utilize narrow beams (divergence of 0.14 arc second at the 3 db power points), a pointing capability commensurate with the beam angular divergence is required. Pointing a laser to this accuracy from the spacecraft to a ground site would be virtually impossible without tracking a reference line of sight from the ground.

Because of atmospheric turbulence the ground-based beacon's image in the spacecraft telescope moves laterally (image dancing). In the spacecraft this motion gives rise to tracking signals which, after being fed to an image motion compensation (fine beam deflection) system, would cause the spacecraft line-of-sight to erroneously follow the image dancing. For a given apparent motion, the angle through which the tracker has to move decreases with altitude. The minimum altitude at which the fluctuation is reduced to an acceptable 0.01 arc second (1/10 the Airy disc of the proposed 1.0 meter telescope) is 2,000 miles.

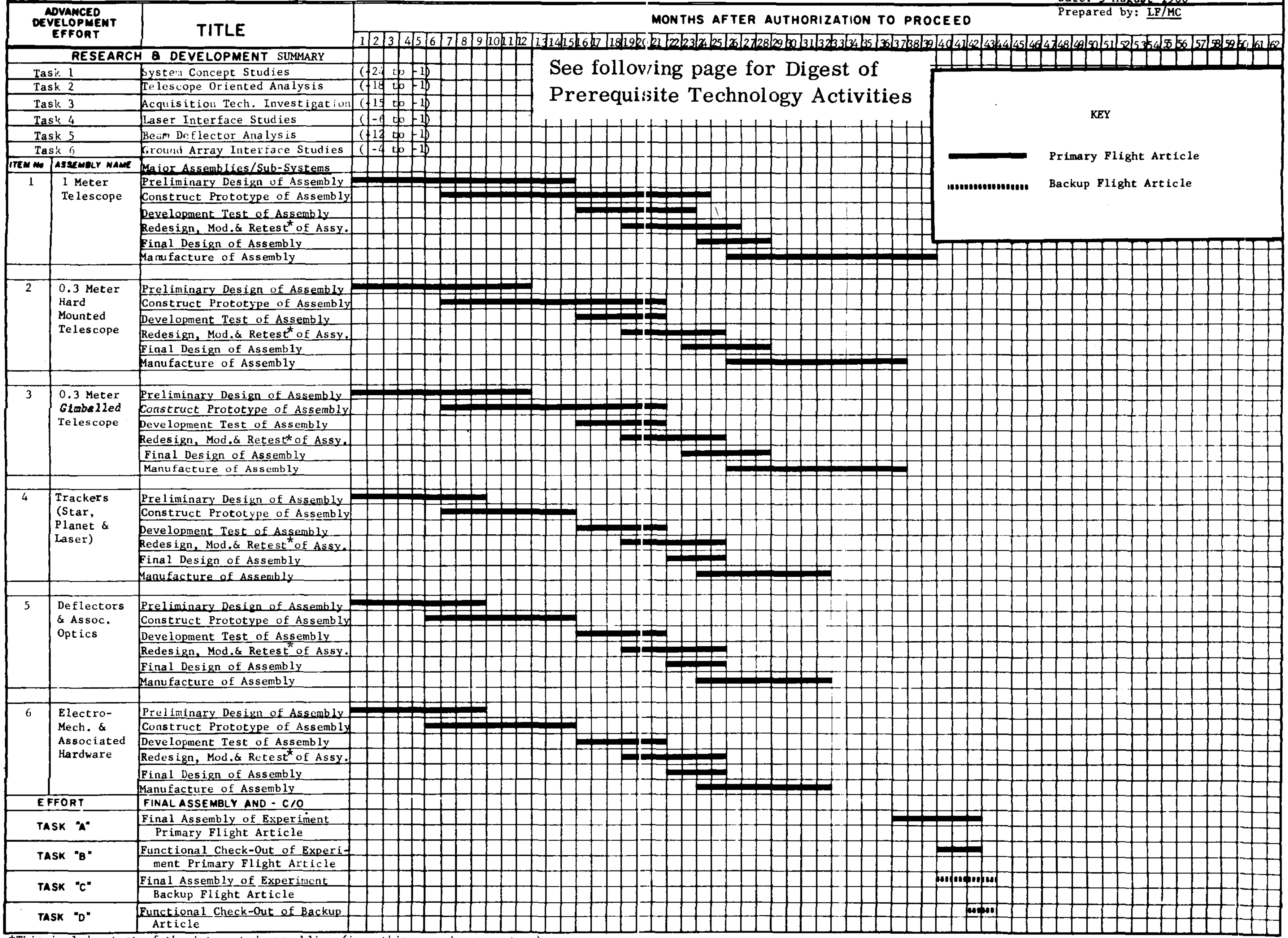
This experiment involves the precision of tracking a ground-based beacon with a telescope mounted in an earth-orbiting spacecraft. This same telescope will support the optical communication experiments described in the previous experiment summaries. The tracking precision will be measured for various beamwidths. Since the acquisition and tracking function at the spacecraft must take into account the varying earth shine conditions present at Earth for different illumination phases of Earth as seen from Mars, this experiment will be performed under the varying earth shine conditions which will naturally be present in synchronous orbit over a diurnal cycle. In this experiment, lead angles will be inserted on an open-loop basis. Better tracking precision will be obtained by closed-loop operation between the spacecraft and ground station. This is the object of the following experiment.

PROJECT: OTAES PH I EXTENSION

LEGEND: PRECISION TRACKING OF A GROUND BEACON
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-5

Detail Schedule E-5
Sheet 1 of 1 Sheet
Date: 3 August 1966
Prepared by: LF/MC



*This includes test of the integrated assemblies (i.e. this experiment package)

DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 24 months

Research and Development

a. Systems concept studies - necessary prerequisite for establishing a 2-way tracking link. (24 months)
   (1) Effect of atmosphere on coherence of laser beam. Spatial and temporal degradation analysis.
   (2) Examination of other atmospheric effects. (scintillation)
      (a) Beam diversion
      (b) Angular jitter (earth-to-space and space-to-earth).
   (3) Human factors studies (astronauts' mobility, isolation, and function).
   (4) Deep space simulation experiments.

b. 1-meter telescope analysis (18 months).
   (1) Boresight alignment (transmitter and tracking axes) studies.
   (2) Optical test and interface with methods in space.
   (3) Alignment of telescopes to one another.

c. 0.3-meter hardmounted telescope analysis (6 months).
   (1) Boresight to 1-meter telescope.
   (2) Study and definition of additional experiment tasks for incorporation.

d. 0.3-meter gimbal telescope analysis (9 months).
   (1) Boresight to 1-meter telescope.
   (2) Study and definition of additional experiment tasks for incorporation.

e. Acquisition techniques investigation (15 months).
   (1) Probability comparison of various methods.
   (2) Combination of microwaves and sun line-of-sight for initial stabilization.
   (3) Hand-off of celestial targets in synchronous orbits for other applicable missions.
   (4) Planet tracker accuracy analysis.
      (a) Tracking centroid of illumination.
      (b) Geometrical center identification.
      (c) Percentage accuracy as a function of range.

f. Laser interface studies (6 months).
   (1) Techniques for changing power distribution in beam group section (for minimixing losses due to obscuration of bisecondary mirrors etc.).
   (2) Achromatic collimating optics for optimizing wavelength range.

g. Beam deflector analysis (12 months).
   (1) Hybrid systems for minimizing nonlinearity of deflectors by means of beam angling and translation.
   (2) Servo analysis required for stability and frequency response for hybrid systems.

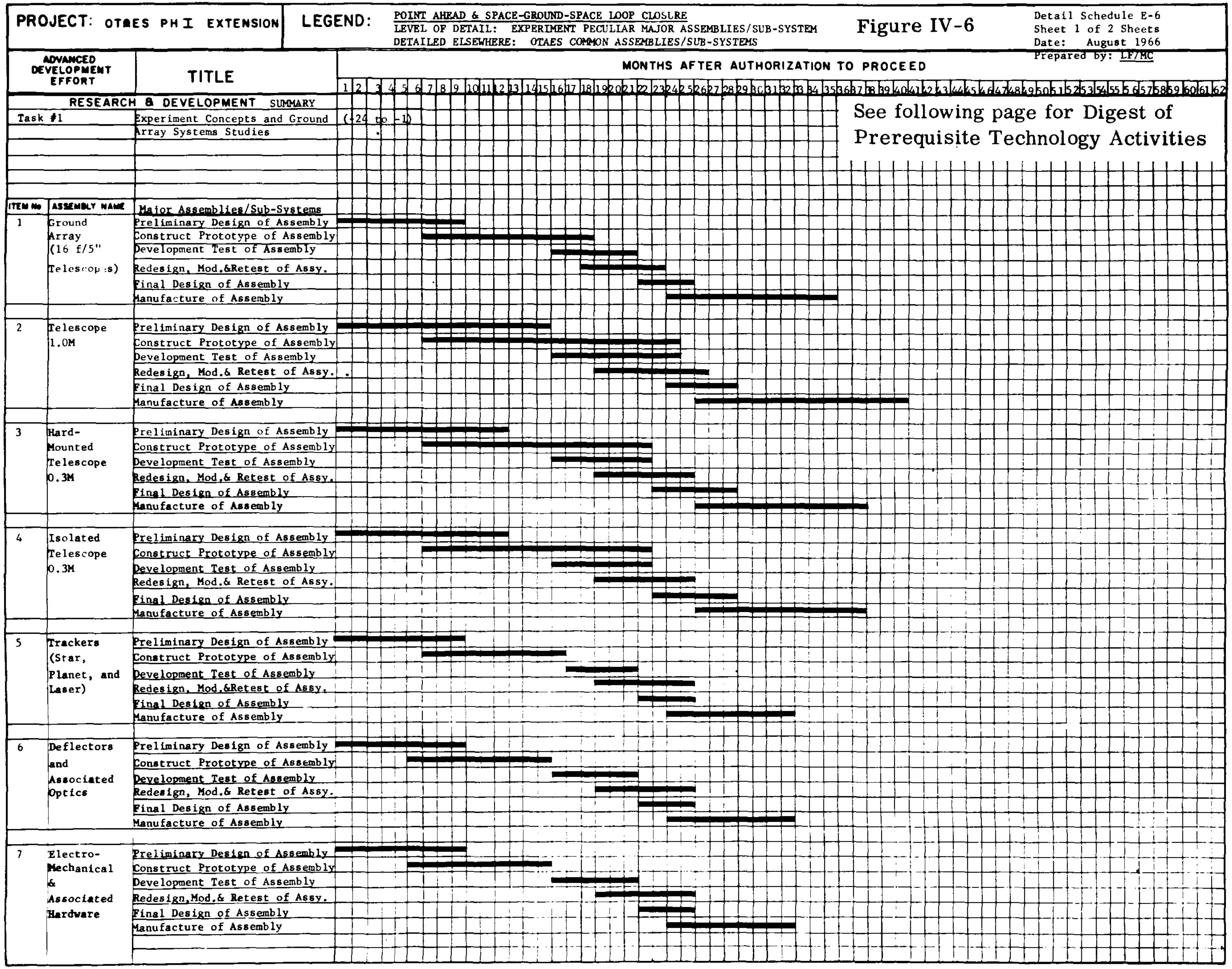
h. Ground array interface studies (4 months).

6. Point Ahead and Space-to-Ground-to-Space Loop Closure Experiment

In a two-way communications link for deep space missions the relative orbital velocity between the space vehicle and Earth, coupled with the long signal transit delays, require that the spacecraft transmitter point ahead of the apparent spacecraft-ground transmitter line of sight in order for the ground receiver to receive the spacecraft transmission. For a typical Mars flyby, the lead angle will be on the order of 40 arc seconds near the terminal phase. Continuous and accurate reception from the spacecraft requires that the point ahead be referenced to the coordinate reference frame established in the Precision Tracking of a Ground Beacon experiment. The point ahead precision requires that control be effected through a closed space-to-ground-to-space control loop.

Image dancing due to atmospheric disturbances operating in a manner analogous to that discussed in the summary of the Precision Tracking of a Ground Beacon experiment impose the need for testing point ahead from earth orbit.

This experiment is an extension of the precision tracking experiment in which an earth orbiting telescope tracks a ground beacon. In this experiment the ability to point a spacecraft laser beam to a ground terminal is tested. This is done by detecting the error on the ground and closing the control loop around this ground detected error signal. Several types of optical detection at the ground receiver will be investigated. Heterodyne detection involves use of a matrix of small telescopes and a local laser oscillator signal beating against the incoming signal in each telescope. Direct detection methods, one using a 4-photon bucket arrangement and a second using a single photon bucket with a conically scanned laser beam, are being considered.


PROJECT: OTAES PHI EXTENSION
LEGEND:
POINT AHEAD & SPACE-GROUND-SPACE LOOP CLOSURE
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEM
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS
Figure IV-6
Detail Schedule E-6
Sheet 1 of 2 Sheets
Date: August 1966
Prepared by: LF/MC
ADVANCED DEVELOPMENT EFFORT
TITLE
MONTHS AFTER AUTHORIZATION TO PROCEED
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62
RESEARCH & DEVELOPMENT SUMMARY
Task #1
Experiment Concepts and Ground Array Systems Studies
(-24 to -1)
See following page for Digest of Prerequisite Technology Activities
ITEM No
ASSEMBLY NAME
Major Assemblies/Sub-Systems
1
Ground Array (16 f/5" Telescopes)
2
Telescope 1.0M
3
Hard-Mounted Telescope 0.3M
4
Isolated Telescope 0.3M
5
Trackers (Star, Planet, and Laser)
6
Deflectors and Associated Optics
7
Electro-Mechanical & Associated Hardware
Preliminary Design of Assembly
Construct Prototype of Assembly
Development Test of Assembly
Redesign, Mod.&Retest of Assy.
Final Design of Assembly
Manufacture of Assembly

PROJECT: OTAES PH I EXTENSION

LEGEND: POINT AHEAD & SPACE-GROUND-SPACE LOOP CLOSURE (Continued)
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB SYSTEM
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-6

Detail Schedule E-6
Sheet 2 of 2
Date: August 1966
Prepared by: LF/MC

ITEM No.	ASSEMBLY NAME	TITLE	MONTHS AFTER AUTHORIZATION TO PROCEED (1–62)
	EFFORT	FINAL ASSEMBLY AND C/O	
	TASK "A"	Final Assembly of Experiment Primary Flight Article	
	TASK "B"	Functional Check-Out of Experiment Primary Flight Article	
	TASK "C"	Final Assembly of Experiment Backup Flight Article	
	TASK "D"	Functional Check-Out of Backup Article	

DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 24 months

Research and Development

Experiment concepts and ground array systems studies (24 months).

(1) Number of telescopes, distribution of telescope array and loop closure, and pointing correction studies.
(2) Heterodyne versus direct detection by photon bucket method comparison.
(3) Beam pointing by direct detection (by four telescopes, or one telescope with superimposed beam oscillation).
(4) Calibration and individual telescope gain in distributed array studies.
    (a) Local oscillator control investigation.
    (b) Photo-multipliers tracker gain analysis.

Remarks: The other required technology advances required are those associated with the Precision Tracking of a Ground Beacon experiment and are listed therein.

KEY

Primary Flight Article (solid bar)

Backup Flight Article (hatched bar)

7. Transfer Tracking from One Ground Station to Another Experiment

A deep space vehicle in optical communication with Earth must possess the capability of transferring track between Earth stations to maintain continuity of operation despite cloud overcast and the Earth's rotation. A chain of Earth stations must be established and so located that a minimum of two stations with reasonable zenith angles and high probability of clear weather will have a direct line of sight to the vehicle.

Meaningful experimentation with precision tracking of a ground beacon can only be conducted from altitudes above 2,000 miles. The transfer tracking demonstration is predicated upon accurate tracking and, consequently, also requires such space testing.

In this experiment a laser beam received on the Earth will be transferred to a second ground station. Since a 4 mile ground station separation is required for the Point Ahead and Space-to-Ground-to-Space Loop Closure experiment, the transfer will be performed at a 4 mile separation. Both stations will have co-located receivers and transmitters for the tracking transfer demonstration. The function is nearly identical to the point ahead except that the transfer commands will be given to the coarse-fine beam deflection control system. The transit time delays of 8 minutes at 1 AU distance must be simulated for this experiment.

PROJECT: OTAES PH I EXTENSION

LEGEND: TRANSFER TRACKING FROM ONE GROUND STATION TO ANOTHER
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-7

Detail Schedule E -7
Sheet 1 of 2
Date: 3 August 1966
Prepared by: M. Cohen

MONTHS AFTER AUTHORIZATION TO PROCEED (1–62)

ADVANCED DEVELOPMENT EFFORT		TITLE
RESEARCH & DEVELOPMENT SUMMARY		
Task #1		System Concept Studies (-18 to
Task #2		Ground Station Req. Analysis (-12 to -1)
Task #3		Deep Space Simulation Studies (-6 to -1)
ITEM No	ASSEMBLY NAME	Major Assemblies/Sub-Systems
1	Ground Array (16 f/5" Telescopes)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
2	Telescope 1.0M	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
3	Hard-Mounted Telescope 0.3M	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
4	Isolated Telescope 0.3M	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
5	Trackers (Star, Planet, and Laser)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
6	Deflectors and Associated Optics	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
7	Electro-Mechanical & Associated Hardware	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly

DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 24 months

Research and Development

a. Continuing system concept studies (24 months).
   (1) Individual ground station coding.
   (2) Sequencing and synchronizing direct function between separate ground stations and spacecraft to ground station.
   (3) Number and location of ground tracking sites.

b. Ground station requirements analysis (12 months).

c. Deep space simulation studies (6 months).

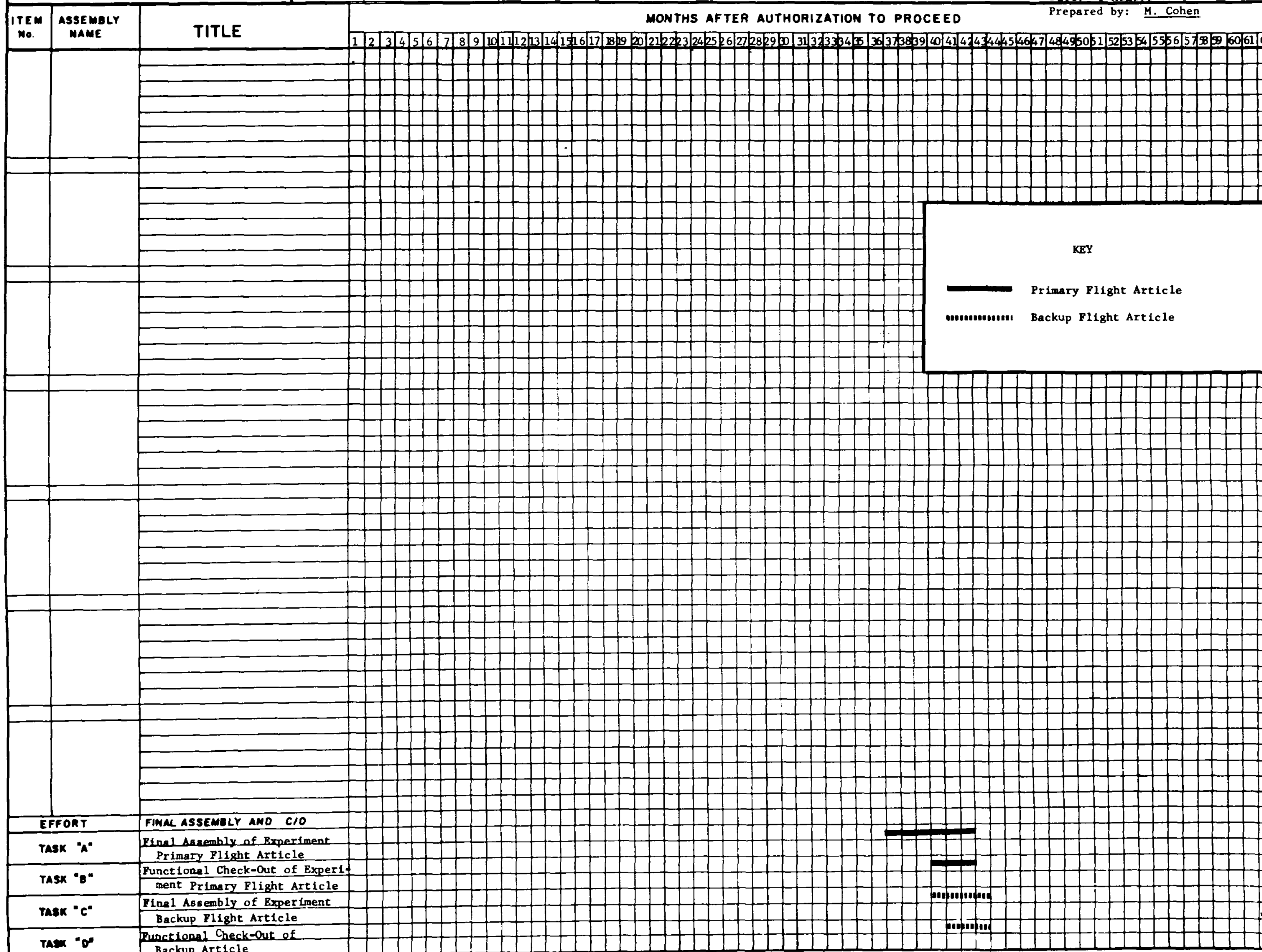
Remarks: The other required technology advances are those associated with the Precision Tracking of a Ground Beacon experiment and are listed therein.

PROJECT: OTAES PH I EXTENSION

LEGEND: TRANSFER TRACKING FROM ONE GROUND STATION TO ANOTHER (Continued)
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-7

Detail Schedule E-7
Sheet 2 of 2
Date: 3 August 1966
Prepared by: M. Cohen



8. Phase Correlation Measurements Experiment

Although the atmospheric effects on the propagation of electromagnetic waves have been the subject of scientific and engineering interest for hundreds of years, increases in the spectral capabilities, resolution, and sensitivity of available instruments and sensors have revealed gaps in the knowledge of the atmosphere and have generated renewed interests in measurements previously attained with great difficulty. The effects on the transmission of optical frequencies can be determined by a detailed examination of the attenuation and refraction characteristics of the atmosphere. The absorption properties of the atmosphere have yielded much of the information now available. There is still much information to be gained, however, through measurements of refraction effects.

Temporally and spatially random variations in the index of refraction of the atmosphere have limited the performance of optical instruments. Now that optical wavelengths can be applied to communication, tracking, and measuration, the need for detailed knowledge of these variations has become even more evident. Theoretical knowledge of the effect of these variations on optical wavefronts has progressed to the point where measurements must be made of the physical quantities and their functional relationships. To date, theoretical derivations have been based on correlation or structure functions extrapolated from the microwave frequencies in which the presence of water vapor is considerably more significant than at optical frequencies. The few available measurements at optical frequencies have been made with stellar or thermal sources which have such poor temporal coherence that extrapolation to the more coherent laser light applications is of questionable validity.

To correlate experiment and theory, which usually assumes a plane wave incident on a random medium, it is necessary that the turbulent medium be in the far field of the transmitting antenna. This cannot be done with a transmitting aperture located within the atmosphere. To make such measurements would require a monochromatic light source in orbit and a receiver which samples and correlates two points on a wavefront. In order to avoid spatial integrating effects, the measurements should be made with a small aperture.

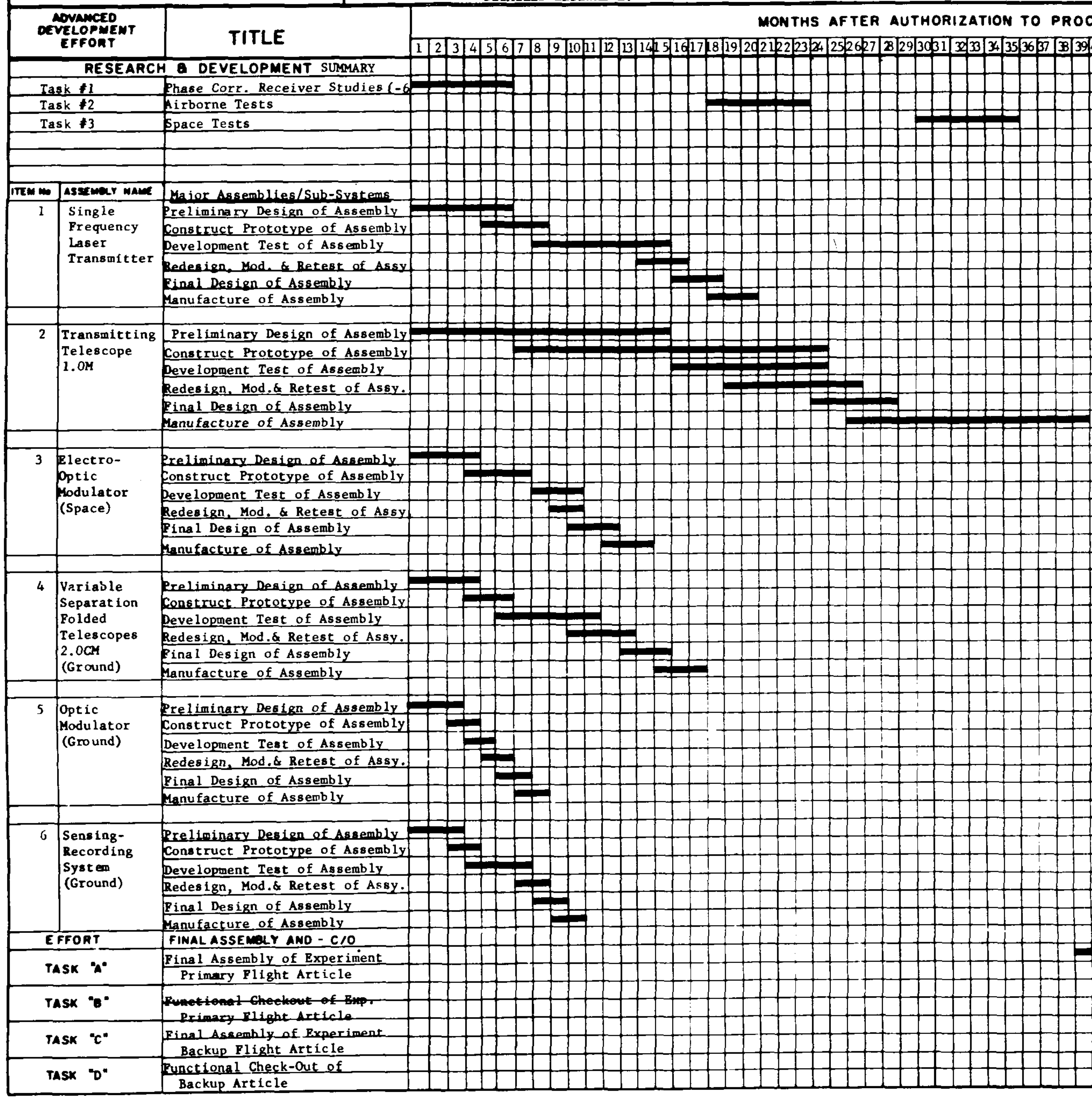
In this experiment the phase variations of a highly monochromatic laser source is measured. Phase variations are measured by an optical interferometer with a variable baseline. With certain modifications, largely in the ground-based instrumentation, amplitude correlations could also be measured. From these measurements, the limitations on coherent apertures could be determined for ready application in the design of superheterodyne systems and an assessment made of the accuracy of scientific measurements which depend on signal frequency.

PROJECT: OTAES PH I EXTENSION

LEGEND: ATMOSPHERIC MEASUREMENTS
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-8

Detail Schedule E-8
Sheet 1 of 1
Date: 3 August 1966
Prepared by: R. Kallin



DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 12 months

Research and Development

a. Phase correlation receiver development (12 months).

b. Model phase correlation receiver fabrication (4 months).

c. Phase correlation test program using an airborne signal source (6 months).

d. Phase correlation tests using an earth orbiting signal source (6 months)

Remarks: Except for the extension of phase perturbation measurements to other frequency bands, no great advances are required for this experiment except those specified in the associated experiments concerning beam pointing, diffraction limited telescope operations in space and laser communications. Advances in the sensitivity of detectors and the transmissivity of optical components at this frequency will increase the possibility of obtaining more accurate measurements under poor conditions of atmospheric transmissivity.

9. Pulse Distortion Measurements Experiment

The advent of optical techniques for communication and tracking has been induced by the need for wide-band information channels. There are currently identifiable needs for megahertz bandwidth transmissions over planetary distances. Furthermore, estimates of future terrestrial communication requirements lead rapidly to the conclusion that the frequency bands below the optical will one day be exhausted. Optical frequencies will be required as a matter of course to provide the needed bandwidth. Optical links passing through the Earth's atmosphere may be limited in bandwidth by the effects of the Earth's atmosphere. In order to provide the data required in the design of such links, the characteristics of the transmission channel must be determined as independently of equipment characteristics as is possible.

Since these pulse distortion measurements pertain to communication theory, the receiver must be located in the far field of the transmitting antenna. The difficulties of reliably extrapolating measurements made on a horizontal near field path to a high elevation far field path are formidable enough to make such extrapolations of doubtful validity in the design of optical links. It follows that such measurements cannot be made within the atmosphere; hence, a spaceborne transmitter is required.

One method of determining the phase and amplitude characteristics of a channel is to transmit a known wide-band waveform through the channel and compare the received wavefrom phase and amplitude characteristics with those of the transmitted characteristics. By accounting for changes due to the equipment used, the characteristics of the channel can be determined. In this experiment short pulses are generated in the spacecraft and the effect of the atmosphere on these pulses is measured on the ground. The transmission, reception, and display of very narrow pulses are within the capability of present technology. In fact, a pulse shorter than 10^{-9} seconds has been demonstrated in the laboratory using a helium-neon laser. This technique will permit the determination of channel characteristics up to bandwidths in the order of 10^9 Hz, well beyond presently definable needs.

PROJECT: OTAES PH I EXTENSION

LEGEND: PULSE DISTORTION MEASUREMENTS
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-9

Detail Schedule E-9
Sheet 1 of 1
Date: 3 August 1966
Prepared by: R. Kallin

MONTHS AFTER AUTHORIZATION TO PROCEED

ADVANCED DEVELOPMENT EFFORT		TITLE	Months (bar)
RESEARCH & DEVELOPMENT SUMMARY			
Task #1		Laser Mode Control Studies	1–10
Task #2		Pulse Distortion Ground Tests	9–14
ITEM No	**ASSEMBLY NAME**	Major Assemblies/Sub-Systems	
1	Mode-Locked Laser Transmitter	Preliminary Design of Assembly	1–6
		Construct Prototype of Assembly	5–8
		Development Test of Assembly	8–15
		Redesign, Mod.& Retest of Assy.	14–16
		Final Design of Assembly	16–18
		Manufacture of Assembly	18–20
2	Transmitting Telescope 1.0M	Preliminary Design of Assembly	1–15
		Construct Prototype of Assembly	7–24
		Development Test of Assembly	16–24
		Redesign, Mod.& Retest of Assy.	19–26
		Final Design of Assembly	24–28
		Manufacture of Assembly	26–39
3	Electro-Optic Phase Modulator	Preliminary Design of Assembly	1–5
		Construct Prototype of Assembly	5–8
		Development Test of Assembly	8–11
		Redesign, Mod.& Retest of Assy.	11–12
		Final Design of Assembly	12–14
		Manufacture of Assembly	14–16
4	Heterodyne Receiver	Preliminary Design of Assembly	1–5
		Construct Prototype of Assembly	5–7
		Development Test of Assembly	7–12
		Redesign, Mod.& Retest of Assy.	11–13
		Final Design of Assembly	13–15
		Manufacture of Assembly	15–17
5	Direct Detection Receiver	Preliminary Design of Assembly	1–4
		Construct Prototype of Assembly	4–6
		Development Test of Assembly	6–10
		Redesign, Mod.& Retest of Assy.	9–11
		Final Design of Assembly	11–13
		Manufacture of Assembly	13–15
6	Receiving Telescope 1.0M	Preliminary Design of Assembly	1–8
		Construct Prototype of Assembly	7–12
		Development Test of Assembly	11–14
		Redesign, Mod.& Retest of Assy.	13–15
		Final Design of Assembly	15–17
		Manufacture of Assembly	17–21
EFFORT		**FINAL ASSEMBLY AND - C/O**	
TASK "A"		Final Assembly of Experiment Primary Flight Article	38–42
TASK "B"		Functional Check-Out of Experiment Primary Flight Article	41–45
TASK "C"		Final Assembly of Experiment Backup Flight Article	40–44
TASK "D"		Functional Check-Out of Exp. Backup Article	41–45

DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 14 months

Research and Development

a. Laser mode control and stabilization techniques development (10 months, now in process).

b. Ground-to-ground measurements of pulse distortion at 0.6328 microns to test broadband detectors and display techniques (6 months).

Remarks:

The other required technology advances required are those associated with laser transmitter development as indicated in the Optical Heterodyne Detection on Earth experiment and the ground link receivers development as indicated in both the Optical Heterodyne Detection on Earth and the Direct Detection from Space to Ground experiments.

10. Primary Mirror Figure Test and Correction Experiment

The outstanding goal in space astronomy, announced by the Space Science Board, is the 3-meter (120-inch) telescope. The light gathering power of an orbital 2.5-to 5-meter (100-to 200-inch) telescope is such that if complemented with a very high resolution capability (i.e., to its diffraction limit) it will permit astronomical observation not heretofore possible with the largest Earth observatories or the present series of OAO's.

The telescope aperture, by virtue of its size, establishes its light gathering capability. However, telescope resolution, exclusive of the particular optical configuration, is affected by mirror and or lens surface shape deviation and smoothness, optical system alignment, optical materials and coatings, and lens material homogeneity. The most formidable problem is that of maintaining primary mirror diffraction limited quality. To do this requires sensible and precise techniques for determining the deviation of the mirror figure from its required shape and, if a deviation exists, the use of suitable methods for correcting the mirror figure so that the undesired deviations are removed.

It has been established that to maintain performance specifications in precision systems, an exact determination of proportional limit must be made. Minute permanent deformations occurring in materials below the conventional proportional limit now require a new limit. This limit has been termed as P.E.L. (Precision Elastic Limit) and is defined as the stress which produces a residual strain or deformation of one microinch per inch. This strain (one microinch) is a permanent set in the material and is sufficient in magnitude to change the power of an optical element. These minute permanent deformations in a large mirror will impart an exceedingly small additional deflection when compared to the effect of gravity (ratio greater than 1000: 1) and are therefore not reliability measured on earth. In addition, the zero-gravity space environment and thermal environment of space will distort the mirror figure. Since these two space conditions cannot be simulated on Earth, a space experiment is necessary.

This experiment is designed to measure the effects of the space environment on a thin, spherical, 1.3-meter beryllium mirror and then to correct the mirror surface to the desired shape. The mirror will be corrected by thermal expansion of rods between the mirror and its base structure. The evaluation of the mirror figure will be accomplished by obtaining interferograms of the mirror surface. Mirror figure patterns will be obtained during final figuring on Earth and during orbit. The change in the interferogram from the ground-based case will be interpreted electronically on the spacecraft and transmitted to a ground-based computer. Calculations will then be performed and the results transmitted back to the spacecraft in the form of commands for thermally expanding the rods behind the mirror, thereby correcting the figure.

PROJECT: OTAES PH I EXTENSION

LEGEND: PRIMARY MIRROR FIGURE TEST & CORRECTION
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-10

Detail Schedule E-10
Sheet 1 of 2 Sheets
Date: 3 August 1966
Prepared by: LF/BJ

See following page for Digest of Prerequisite Technology Activities

ADVANCED DEVELOPMENT EFFORT		TITLE	MONTHS AFTER AUTHORIZATION TO PROCEED (1–62)
RESEARCH & DEVELOPMENT SUMMARY			
Task 1		System Exper. Concept Studies	(-24 to -1)
Task 2		Primary Mirror Examination	(-18 to -1)
Task 3		Temp. Actuator & Control Study	(-12 to -1)
Task 4		Scatter-plt. Interferomtr Test	(-6 to -1)
Task 5		Secondary Mirror Studies	(-9 to -1)
Task 6		Test Facility Studies	(-12 to -1)
ITEM No	ASSEMBLY NAME	Major Assemblies/Sub-Systems	
1	Primary Mirror Model(s)	Preliminary Design of Assembly	
		Construct Assembly	
		Development Test* of Assembly	
		Redesign, Mod.& Retest of Assy.	N/A
		Final Design of Assembly	N/A
		Manufacture of Assembly	(Model Utilized)
2	50" Flyable Primary	Preliminary Design of Assembly	
		Construct Prototype of Assembly	
		Development Test of Assembly	
		Redesign, Mod.& Retest* of Assy.	
		Final Design of Assembly	N/A
		Manufacture of Assembly	(Prototype Utilized)
3	Secondary Mirror, S/C Optical Instrument-ation, Etc.	Preliminary Design of Assembly	
		Construct Prototype of Assembly	
		Development Test of Assembly	
		Redesign, Mod.& Retest* of Assy.	
		Final Design of Assembly	
		Manufacture of Assembly	
4	Scanner, Scatter Plate, Interferom-eter, Etc.	Preliminary Design of Assembly	
		Construct Prototype of Assembly	
		Development Test of Assembly	
		Redesign, Mod.& Retest* of Assy.	
		Final Design of Assembly	
		Manufacture of Assembly	
5	Temp. Sensors, Control & Thermal Actuators	Preliminary Design of Assembly	
		Construct Prototype of Assembly	
		Development Test of Assembly	
		Redesign, Mod.& Retest* of Assy.	
		Final Design of Assembly	
		Manufacture of Assembly	
6	Mechanisms	Preliminary Design of Assembly	
		Construct Prototype of Assembly	
		Development Test of Assembly	
		Redesign, Mod.& Retest* of Assy.	
		Final Design of Assembly	
		Manufacture of Assembly	
		(See Sheet 2 of 2)	

* This includes test of the interna[illegible] assemblies (i.[illegible] [illegible] nacka[illegible])

PROJECT: OTAES PH I EXTENSION

LEGEND: PRIMARY MIRROR FIGURE TEST & CORRECTION
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-10

Detail Schedule E-10
Sheet 2 of 2 Sheets
Date: 3 August 1966
Prepared by: LF/BJ

MONTHS AFTER AUTHORIZATION TO PROCEED (1–62)

ITEM No.	ASSEMBLY NAME	TITLE	
7	Special Test Equipment & Facilities	Major Assemblies/Sub-Systems	
		Preliminary Design of Assembly	
		Construct Prototype of Assembly	
		Development Test of Assembly	
		Redesign, Mod. & Retest* of Assy.	
		Final Design of Assembly	N/A
		Manufacture of Assembly	(Prototype Utilized)

EFFORT	FINAL ASSEMBLY AND C/O
TASK "A"	Final Assembly of Experiment Primary Flight Article
TASK "B"	Functional Check-Out of Experiment Primary Flight Article
TASK "C"	Final Assembly of Experiment Backup Flight Article
TASK "D"	Functional Check-Out of Backup Article

DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 24 months

Research and Development

a. Continuing system experiment concept studies (including optical tolerance evaluation and allocation) (24 months).

b. Primary mirror model examination (18 months).
(1) Thermal studies to determine need for mirror temperature control including ground tests for optimum thermal sensing and control configuration.
(2) Scaling studies (analysis, fabrication, and test of small model mirrors.
(3) Material surveys.
(4) Figure control implementation study.
(5) Fabrication methods survey.
(6) Study of mirror support methods.
(7) Effects of launch and orbital environment on figure and optical quality.

c. Temperature actuators and control studies (12 months).
(1) Computer program for determination of influence coefficients.
(2) Actuators temperature sensor analysis.
(3) Actuators material selection.
(4) Thermal insulation problems investigation.
(5) Thermal control servo loop analysis.

d. Implementation study of scatter-plate interferometer test in orbit. Study and development of other optical instrumentation for figure test in orbit (6 months).

e. Secondary mirror studies (9 months).
(1) Thermal study.
(2) Material survey.
(3) Study of in-orbit automatic erection and optical alignment devices.

f. Test facility requirements studies (12 months).

KEY

Primary Flight Article (solid bar)

Backup Flight Article (hatched bar)

*This includes test of the integrated assemblies (i.e. this experiment package)

11. Thin Mirror Nesting Principle and Erection and Alignment of Large Optics in Space Experiment

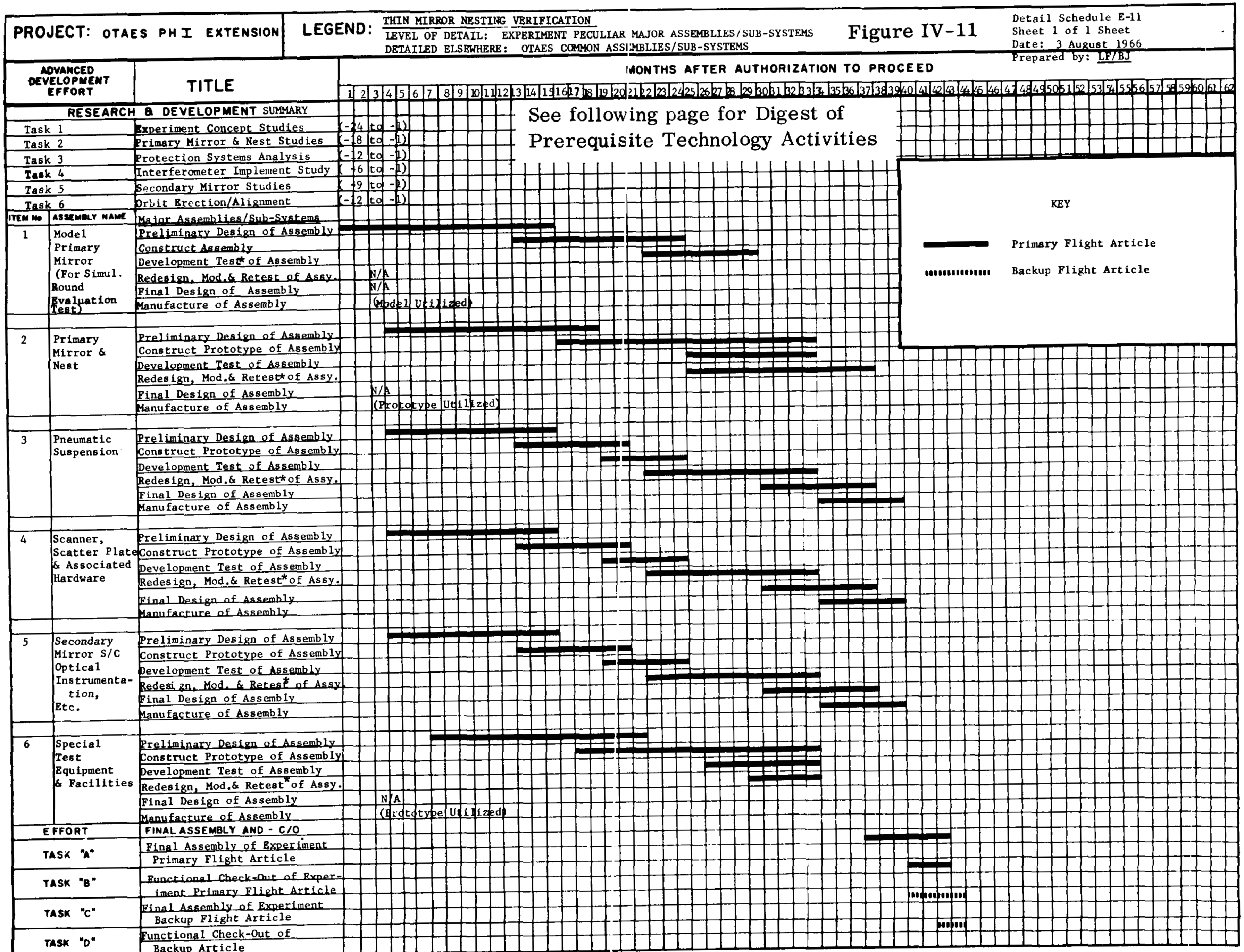
The resolution of an optical system is proportional to its aperture and modified by the quality and uniformity of each optical element. Light gathering power increases as the square of the aperture. The speed and resolution of optical systems can be increased by using larger and higher quality optics. Various astronomers have indicated that certain astronomical observations not achievable with Earth observations or within the capability of the OAO series require 2.5-to 5-meter (100-to 200-inch) aperture telescopes with diffraction-limited resolution ability. However, the weight and volume required by systems of this size impose severe requirements even on the more advanced launch systems.

One means for alleviating these weight constraints is to configure a very thin mirror. This, of course, has the attendent problems of support during manufacture, handling, and launch. Manufacture and test of a very thin mirror in a nest where the mirror is uniformly supported at all times simulates, in effect, the zero gravity condition of space. This also permits the construction of such a mirror on Earth so that it will perform under the weightlessness conditions of space.

The purpose of this experiment is to investigate the theory and develop the technology so that very thin mirrors fabricated on Earth in a nest (so as to negate the distorting force of gravity) can be handled, launched, and erected in a zero g environment where stresses induced by gravity are removed. A thin mirror will be manufactured, handled, launched, and inserted into orbit while limiting all applied stressed by a factor of one-nineteenth of the Precision Elastic Limit. (See the preceding experiment).

The reasons for space testing are the same as in the preceding experiment.

In this experiment, a scale model telescope employing a thin, 1.3-meter (50-inch) diameter beryllium mirror will be erected, aligned, and tested in space. During orbit, the astronaut will erect and align the mirror to the optical tolerances associated with earth-bound observatories. The evaluation of the mirror figure will be accomplished by interferograms. Mirror figure patterns will be obtained prior to and during orbit. These patterns will be compared. The results of this experiment will serve as a guide for the design and fabrication of a 2.5-to 5-meter (100-to 200-inch) reflector type telescope for orbital use.



* This includes test of the integrated assemblies (i.e., this experiment package).

DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 24 months

Research and Development

a. Continuing experiment concept studies (includes optical tolerance evaluation and allocation) (24 months).

b. Primary mirror test studies (18 months).
   (1) Thermal studies to determine need for temperature control including ground tests for optimum thermal sensing and control configuration.
   (2) Scaling studies (analysis, fabrication, and test of small model mirrors).
   (3) Material surveys.
   (4) Fabrication methods investigation.
      (a) Mirror nest – mirror interface; selection of release agents and evaluation release technique.
      (b) Distortion effect of polishing and figuring.
      (c) Determination of diameter to thickness ratio to meet requirements.
   (5) Zero g simulation testing techniques and facility requirements.
   (6) Study of mirror support methods.

c. Pneumatic suspension systems and alternate protection systems analysis, launch environment effects, and model tests (12 months).

d. Implementation study of scatter-plate interferometer and other optical instrumentation for figure test in orbit (6 months).

e. Secondary mirror and secondary mirror structure studies (9 months).
   (1) Thermal study.
   (2) Material study.

f. Study of in-orbit erection and/or alignment devices (12 months).
   (1) Manual erection and human factors constraints.
   (2) Automatic erection investigation.
   (3) Optical alignment examination.

g. Test facility studies including optical bench and thermal control computer (12 months).

12. Fine Guidance Experiment

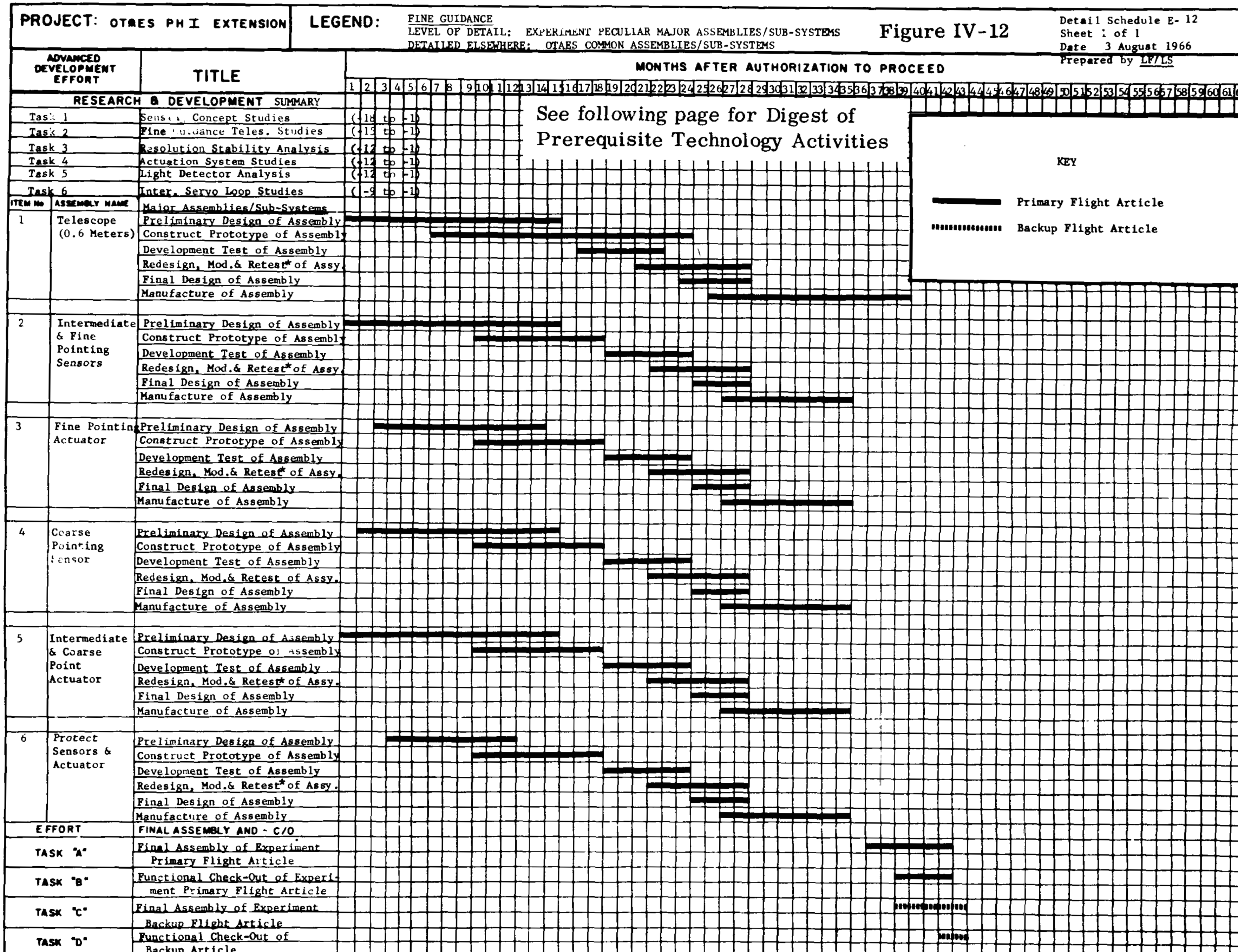
Large manned diffraction-limited astronomical telescopes for application in earth orbit, where atmospheric distrubances are absent, are in the planning stage. To fully utilize the freedom from atmospheric distrubances, the orbiting telescope will require a high degree of pointing accuracy and pointing stability.

Although earthbound testing must be performed on space equipment, the sought after stability performance in the proposed experiment will be lacking or at least masked by such testing. Transmission of microseisms (0.1 to 10Hz) through the mount of an optical bench, flexing of the mount of an optical bench, and flexing of the mount itself under 1 g Earth conditions can each be comparable to or larger than the desired pointing accuracy and stability. Image dancing due to atmospheric turbulence might be eliminated by testing in a vacuum chamber; however, the distortion of a 100 foot long seismic block supporting an optical bench due to the change in pressure load arising from the chamber evacuation may be of the same order as the desired performance. Air bearing table facilities for dynamic stability tests to hold 0.01 arc seconds for 6 hours do not exist, and the degrading effects of turbine torques as well as torques due to mass shifts, magnetic troques, and other air bearing distrubances make it questionable whether the desired performance will be difficult to achieve in space. In the presence of Earth's degrading influences, the performance may never be achieved.

The Fine Guidance experiment will serve the purpose of space development and testing of a highly stable star pointing system applicable to large telescopes (at least 100 inches). For this experiment the comparable performance is a pointing system stable to one one-hundredth of 1 second of arc when guiding on dim stars (± mag AO star) against different background brightnessess.

This experiment is performed on the fine guidance telescope in conjunction with the comparison of isolation techniques. A 10th magnitude star is acquired and tracked for an exposure period for each of the fine guidance schemes being tested. Performance of each is measured by real time monitoring of the error signals and by the size of the exposed image.

This experiment will evaluate the pointing stability as a function of star color temperature and magnitude, evaluate at least two types of fine sensors test reacquisition and fine guidance on consecutive half orbits (which is important in near earth orbit missions), and evaluate two or more beam deflectors.



*This includes test of the integrated assemblies (i.e. this experiment package)

DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 18 months

Research and Development

a. Systems concept studies to establish sensing (18 months).
   (1) Direct versus offset tracking as a function of star magnitude studies.
   (2) Tracking capability relationship to background noise and star magnitude and color temperature investigation.
   (3) System effects of various orbits.
   (4) Analysis and allocations of errors.

b. Study of thermal behavior (6 months).

c. Fine guidance telescope studies (15 months).
   (1) Study of tertiary system configuration and alignment techniques.
   (2) Study of scanning methods.
   (3) Analysis of maximum resolution.

d. Fine sensor studies (resolution stability) (12 months).
   (1) Four side pyramidal deflector.
   (2) Image dissector tube.
   (3) Crossed-axis vibrating aperture.
   (4) Math-matching (large field scanner, using image orthicon or vidicon).

e. Study of actuation system, control moment gyros, reaction wheels, and fine beam deflector (coarse, intermediate, and fine) actuation and logic control system (12 months).

f. Light detector analysis – diasporameters, cantilever mirror, sheared plate (sensitivity, spectral diamagnetic response) (12 months).
   (1) Solid state (silicon, gallium arsenide).
   (2) Photocathode with electron multipliers. Photo detectors with integral solid state multipliers.
   (3) Light amplifiers.
   (4) Imaging devices.

g. Study of fine and coarse intermediate servo loops (9 months).

h. Study of protect sensors and actuators (9 months).

i. Earthbound development tests (12 months).

j. Test facility study (12 months).

13. Comparison of Isolation Techniques Experiment

Highly stable and accurate pointing of space telescopes is essential to future space astronomy. For high dispersion spectroscopy with a 120-inch diffraction-limited telescope, for example, the stability requirements along the narrow dimensions of the slit are ± 0.02 arc seconds. The stability of an uncontrolled Apollo class spacecraft in which man is free to move is about ± 1 degree. This leaves a five-orders-of-magnitude discrepancy to be resolved.

By imposing reasonable constraints on man's movements and use of the spacecraft attitude control system, the spacecraft stability may be improved one order of magnitude to ± 6 arc minutes. Mounting the telescope in a set of gimbals will further enhance its stability to about ± 5 arc seconds. Use of a beam deflector in a fine guidance loop will further stabilize the image to an extent determined by the ratio of servo bandwidth to distrubance bandwidth. However, analysis of practical limitations on servo bandwidth for fine guidance applications, coupled with the spectrum of expected man-produced distrubances, shows that disturbances occuring at 1 cycle per second must still be attenuated by two orders of magnitude between the spacecraft and the telescope.

The only way to achieve this attenuation is to physically isolate the telescope from the spacecraft. Both passive and active techniques to achieve this isolation have been investigated. These range from simple mechanical gimbals which provide rotational freedom for the telescope to servo-controlled mounts which measure the disturbances acting on the telescope and, through feedback control, null the effects of these disturbances.

With the exception of the mechanical gimbals, which require little development for space use, all the techniques studied are designed specifically to take advantage of the low g orbital environment. Hardware development of these isolation techniques must include testing in a low g environment. Practical ground-based simulation schemes are limited to two axes of translation and one of rotation. This kind of simulation is useful and necessary for the development of techniques for space testing. However, for actual space astronomy missions, where important operational decisions (e.g., attached or detached mode) may be based on presumptions about performance of the isolation system, the results of a partial groundbased simulation does not provide the high level of confidence that is desirable.

In this experiment, the performances of two or more isolation techniques are evaluated and compared. The fine guidance telescope is mounted with two or more suspension systems in parallel so that each can be inserted and removed on command. This experiment is performed in conjunction with the fine guidance experiment, which serves as a sensor for measuring the performance of the isolation systems while the crewmen execute both programmed and natural movements.

PROJECT: OTAES PH I EXTENSION

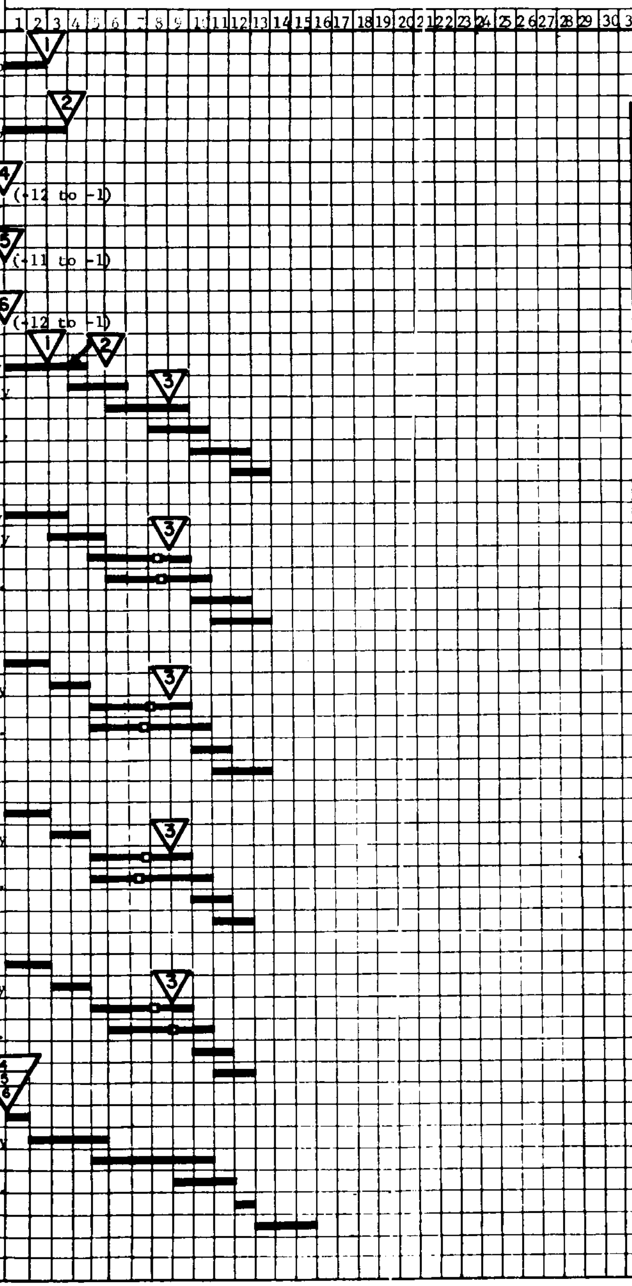
LEGEND: COMPARISON OF ISOLATION TECHNIQUES
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-13

Detail Schedule E-13
Sheet 1 of 2
Date: 5 August 1966
Prepared by: J.T. Riles

ADVANCED DEVELOPMENT EFFORT		TITLE
RESEARCH & DEVELOPMENT SUMMARY		
Task #1		Theoretical Analysis (-4 to
Task #2		Laboratory Tests (Hard Mount) (-3 to
Task #3		Spring Mount Oriented Analysis (-12 to -1)
Task #4		Diamagnetic Bearing Oriented Analysis (-11 to -1)
Task #5		Active Suspension Oriented Analysis (-12 to -1)
Item #	Assembly Name	Major Assemblies/Sub-Systems
1	Isolation and Conventional Bearings	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
2	Caging Device (Hard Mount)	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
3	Torque Motor	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
4	Angle Resolver	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
5	Data Bridge	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
6	Springs	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly

MONTHS AFTER AUTHORIZATION TO PROCEED



KEY

Activity Time
Delay Time
Backup Flight Article

1, 2: Completion of Preliminary Design of Bearings Constrained by Theoretical Analysis and Laboratory Tests.

3: Development Test of Prototype Experiment Constrained by Completion of Development Tests of Bearings.

4, 5, 6: Preliminary Design of Springs, Position Sensor, Damping Device, and Suspension Locking Device is Constrained by Completion of Spring Mount Oriented Analysis, Diamagnetic Bearing Oriented Analysis and Active Suspension Oriented Analysis.

DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 12 Months

Research and Development

a. **Hard mount oriented analysis.**
   (1) Theoretical analysis (6 months).
   (2) Laboratory tests (6 months).

b. **Spring mount oriented analysis.**
   (1) Dynamic environment analysis (5 months).
   (2) Static environment analysis (4 months)
   (3) Conductive spring materials analysis (6 months)
   (4) Motion detection optics analysis (6 months).
   (5) Damping mechanisms studies (4 months).
   (6) Analog simulation (3 months).

c. **Diamagnetic bearing oriented analysis.**
   (1) Magnetic field configuration optimization (6 months)
   (2) Electro-magnet utilization anal ysis (6 months).
   (3) Comparison of knuckle and gimbal configurations (4 months).
   (4) Diamagnetic materials survey (6 months).
   (5) Damper techniques comparison (4 months).
   (6) Position sensor analysis (4 months).
   (7) Analog simulation (3 months).

d. **Active system oriented analysis.**
   (1) Electromagnetic linear actuator analysis (4 months).
   (2) Actuator configuration studies (6 months).
   (3) Comparison of low-threshold accelerometers (3 months).
   (4) Position sensor analysis (4 months).
   (5) Servo analysis (2 months).
   (6) Hybrid diamagnetic/active suspension configuration analysis (3 months).
   (7) Analog simulation (4 months).

Remarks: The other required technology advances are those associated with the Fine Guidance experiment and are listed therein.

PROJECT: OTAES PH I EXTENSION

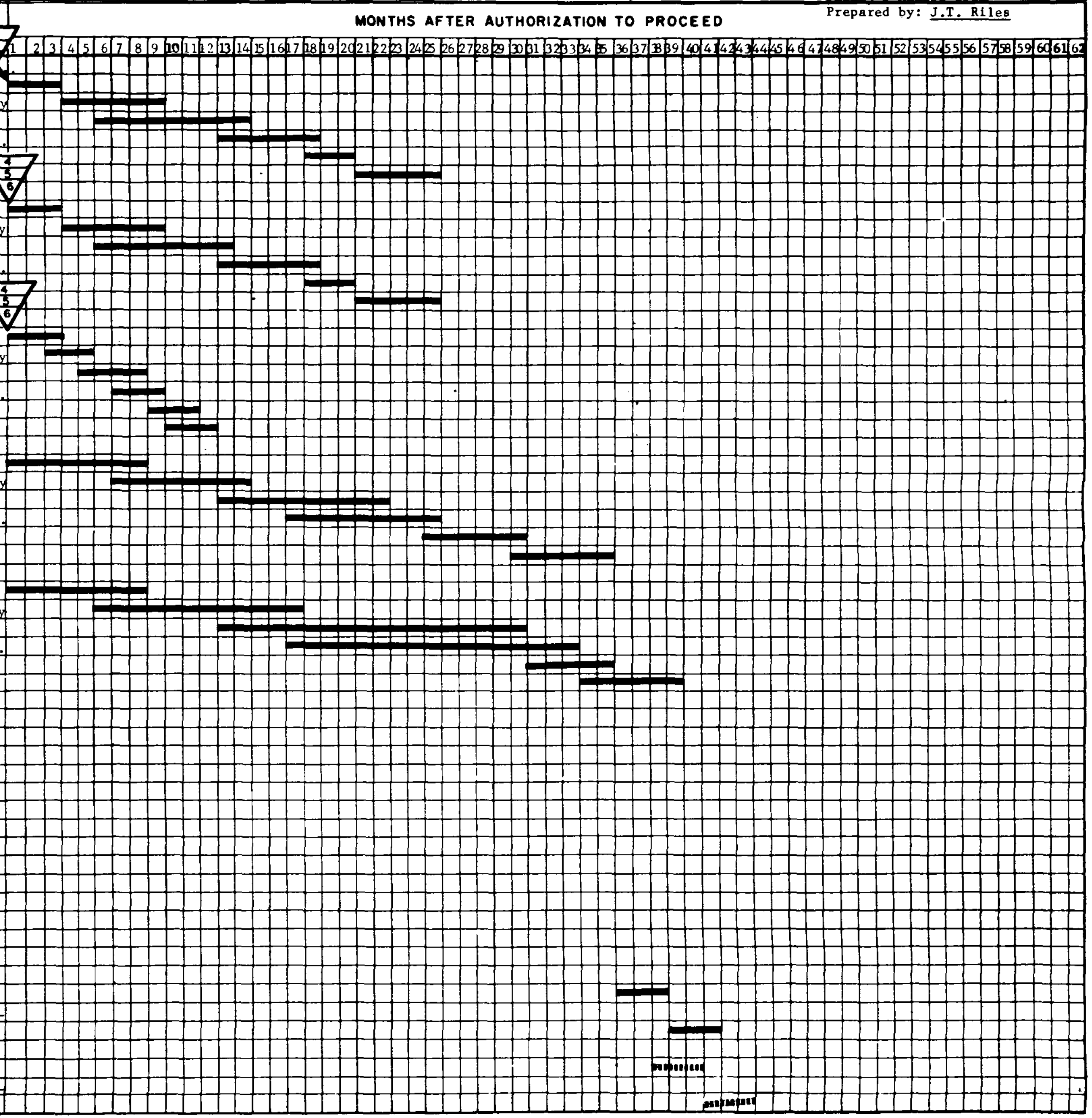
LEGEND: COMPARISON OF ISOLATION TECHNIQUES (CONTINUED)
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-13

Detail Schedule E-13
Sheet 2 of 2
Date: 5 August 1966
Prepared by: J.T. Riles

MONTHS AFTER AUTHORIZATION TO PROCEED

ITEM No.	ASSEMBLY NAME	TITLE
		Major Assemblies/Sub-Systems
7	Position Sensor	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
8	Damping Device	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
9	Suspension Locking Device	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
10	Motion Detection Optics	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
11	Special Test Equipment	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
EFFORT		FINAL ASSEMBLY AND C/O
TASK "A"		Final Assembly of Experiment Primary Flight Article
TASK "B"		Functional Check-Out of Experiment Primary Flight Article
TASK "C"		Final Assembly of Experiment Backup Flight Article
TASK "D"		Functional Check-Out of Experiment Backup Article



14. Stellar Interferometer Experiment

One astronomical goal is to measure stellar diameters and binary separations. The stellar interferometer is used to measure angular diameters through interpretation of interference patterns. Stellar interferometers were constructed and operated successfully by Michelson, Pease, Anderson, and others before Pease's death in 1930. Much useful data on stellar diameters and binary separations was derived with the 20-foot interferometer, but the 50-foot interferometer built in 1930 proved to be a disappointment. F. G. Pease worked with the instrument at Mt. Wilson, but as evidenced by the conspicuously small mention given the interferometer in the annual reports of the thirties, he was plagued with beam vibration and atmospheric turbulence effects.

A stellar interferometer stationed in earth orbit, where these effects can be minimized, will be a valuable tool for increasing our knowledge of stellar and galactic dimensions, Cepheid characteristics, and mechanics of stellar system, to name a few applications. Recommendation No. 5 in Orbital Astronomy of the Space Science Board Meeting at Woods Hole in 1965 called for the development of optical stellar interferometers, citing the importance of stellar diameter measurements.

The effects of the space environment on the instrument cannot be obtained on Earth, nor can they be adequately simulated in the presence of gravity. Data are needed on the effect of continuous station keeping and continuous fine pointing requirements. Comparison of beam concepts must be accomplished in space. The total effect of the orbital environment on a 50-or 100-foot interferometer cannot be fully assessed on Earth. It is necessary to make practical and accurate measurements of the adverse effects of the totality of factors such as thermal deformation, vehicle vibration and rotation, parallax of orbit, orbital motion, gravity gradient, and solar wind before including the instrument or an orbital laboratory at an operational level.

In this experiment an interferometer system with a nominal beam length of 50 feet will be deployed in two stages. Vibration sensors along the beam are used to monitor the activity of the beam as the spacecraft is pointed at a target (stars which have been used with ground-based interferometers) and subjected to rotational torque and simulated random type internal disturbances. After completion of the disturbance program, the image from the two interferometer pencils are focused near each other in the field of view. The smallest circle of confusion is achieved as the spacecraft is stabilized. Long beam experiments are conducted in the same way. At least two beam concepts will be compared.

PROJECT: OTAES PH I EXTENSION

LEGEND: INTERFEROMETER SYSTEM
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

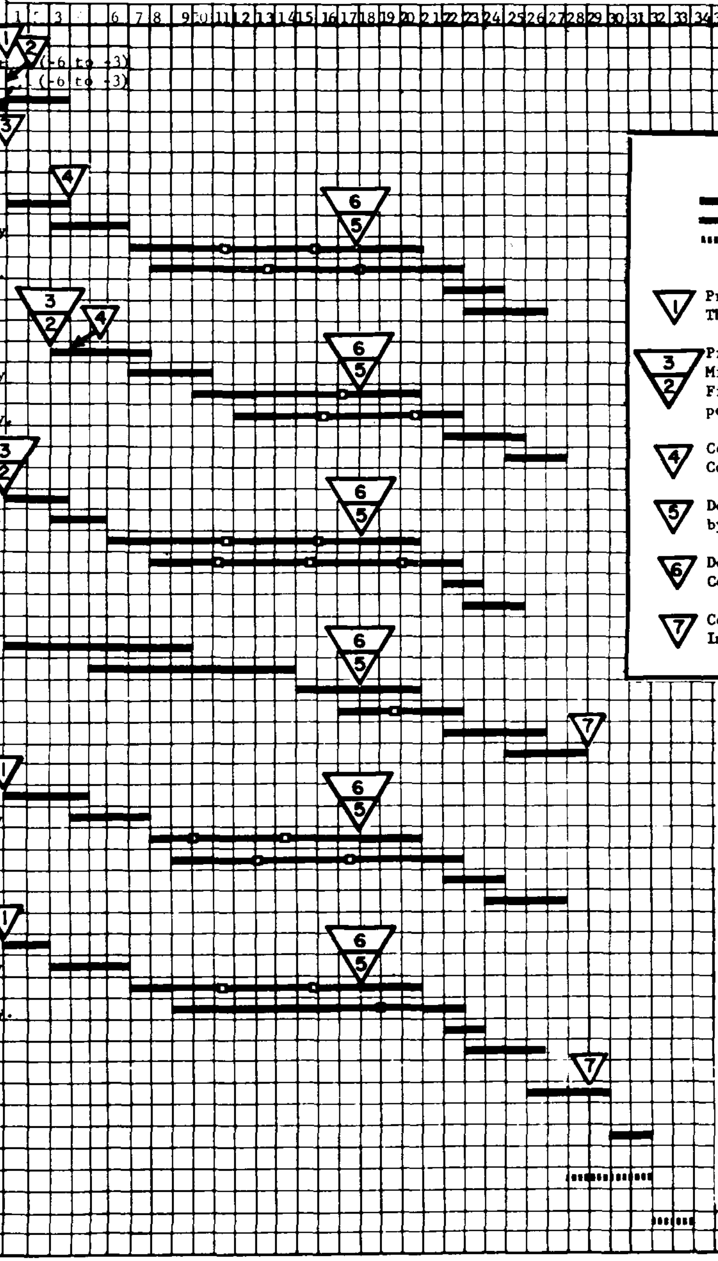
Figure IV-14

Detail Schedule E-14
Sheet 1 of 1
Date: 6 July 1966

Prepared by: G.L. Hempfling

MONTHS AFTER AUTHORIZATION TO PROCEED

ADVANCED DEVELOPMENT EFFORT		TITLE
RESEARCH & DEVELOPMENT SUMMARY		
Task No. 1		Theoretical Analysis of Concept (-6 to -3)
Task No. 2		Mirror Fine Alignment Actuator (-6 to -3)
Task No. 3		Laboratory Experiments (-6
ITEM No	ASSEMBLY NAME	Major Assemblies/Sub-Systems
1	Beam	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
2	Outer Mirror Assembly	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod. & Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
3	Inner Mirror Assembly	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
4	Imaging Assembly	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
5	Telescope Cover Positioning Mechanism	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod.& Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
6	Optics	Preliminary Design of Assembly
		Construct Prototype of Assembly
		Development Test of Assembly
		Redesign, Mod. & Retest of Assy.
		Final Design of Assembly
		Manufacture of Assembly
EFFORT		FINAL ASSEMBLY AND - C/O
TASK "A"		Final Assembly of Experiment Primary Flight Article
TASK "B"		Functional Check-Out of Exper. Primary Flight Article
TASK "C"		Final Assembly of Experiment Backup Flight Article
TASK "D"		Functional Check-Out of Exp. Backup Article



KEY

- Activity Time
- Delay Time
- Backup Flight Article

1. Preliminary Design of Optics Constrained by Completion of Theoretical Analysis of Concept.
2. / 3. Preliminary Design of Outer Mirror Assembly and Inner Mirror Assembly Constrained by Completion of R & D of Mirror Fine Alignment Actuators and Completion of Laboratory Experiments.
4. Completion of Preliminary Design of Outer Mirror Assembly Constrained by Completion of Beam Preliminary Design.
5. Development Test of the Prototype Experiment is Constrained by Development Test of Imaging Assembly.
6. Development Test of the Prototype Experiment is Further Constrained by Availability of Remote Display and Controls.
7. Completion of Final Assembly Constrained by Availability of Imaging Assembly.

DIGEST OF PREREQUISITE TECHNOLOGY ACTIVITIES

Time Span to Completion: 9 months.

Research and Development

a. Theoretical analysis of beam concepts (6 months).
   (1) Materials survey.
   (2) Conceptual design and analysis.
   (3) Computer analysis of performance.
   (4) Compilation of weight/performance data.
   (5) Environmental disturbances investigation.

b. Mirror fine alignment actuator analysis (6 months).
   (1) Survey and evaluation of techniques.
   (2) Materials survey.
   (3) Computer determination of performance coefficients.
   (4) Insulation and power requirements investigation.

c. Laboratory experiments.
   (1) Beam concept design.
      (a) Model design.
      (b) Model construction.
      (c) Environmental tests and comparison.
   (2) Mirror fine alignment actuators.
      (a) Model design.
      (b) Model construction.
      (c) Environmental tests and comparison.

15. Segemented Optics Experiment

In their attempt to add to the body of scientific knowledge about the universe, astronomers have traditionally been limited by the performance of their instruments. In recent years, however, these limitations have not been imposed by the instruments themselves but rather by the characteristics of the earth's atmosphere, through which light from astronomical bodies must be transmitted before it can be studied with earthbound telescopes. Turbulence and absorption by the atmosphere limit telescope performance so severly that the resolution achieved by the 200-inch Hale telescope at Mt. Palomar is poorer by an order of magnitude than its theoretical limit.

A telescope placed in earth orbit or on the Moon, where the atmospheric effects can be eliminated, will be extremely useful to observational astronomy. For this reason, the development of a 120-inch orbiting telescope has been established by the Space Science Board as the outstanding goal in space astronomy.

At present, however, there are questions which must be answered before the diffraction-limited performance of a mirror can be achieved. A mirror made in the usual fashion will be severly distorted by the thermal environment of space. It will also be distorted by the change from the earth's gravity to the zero gravity of space. To determine the amount of distortion and the best means to correct it, the mirror must be subjected to the space environment.

One possible solution to the problems mentioned above is the use of a segmented primary mirror in the telescope. In order to gain information to allow a determination of the usefulness of this concept, it is proposed as part of OTES to design, orbit, and test a small segmented telescope. The size and shape of the segments desirable for a large mirror will be determined and a few of these will be assembled into a mirror in OTES.

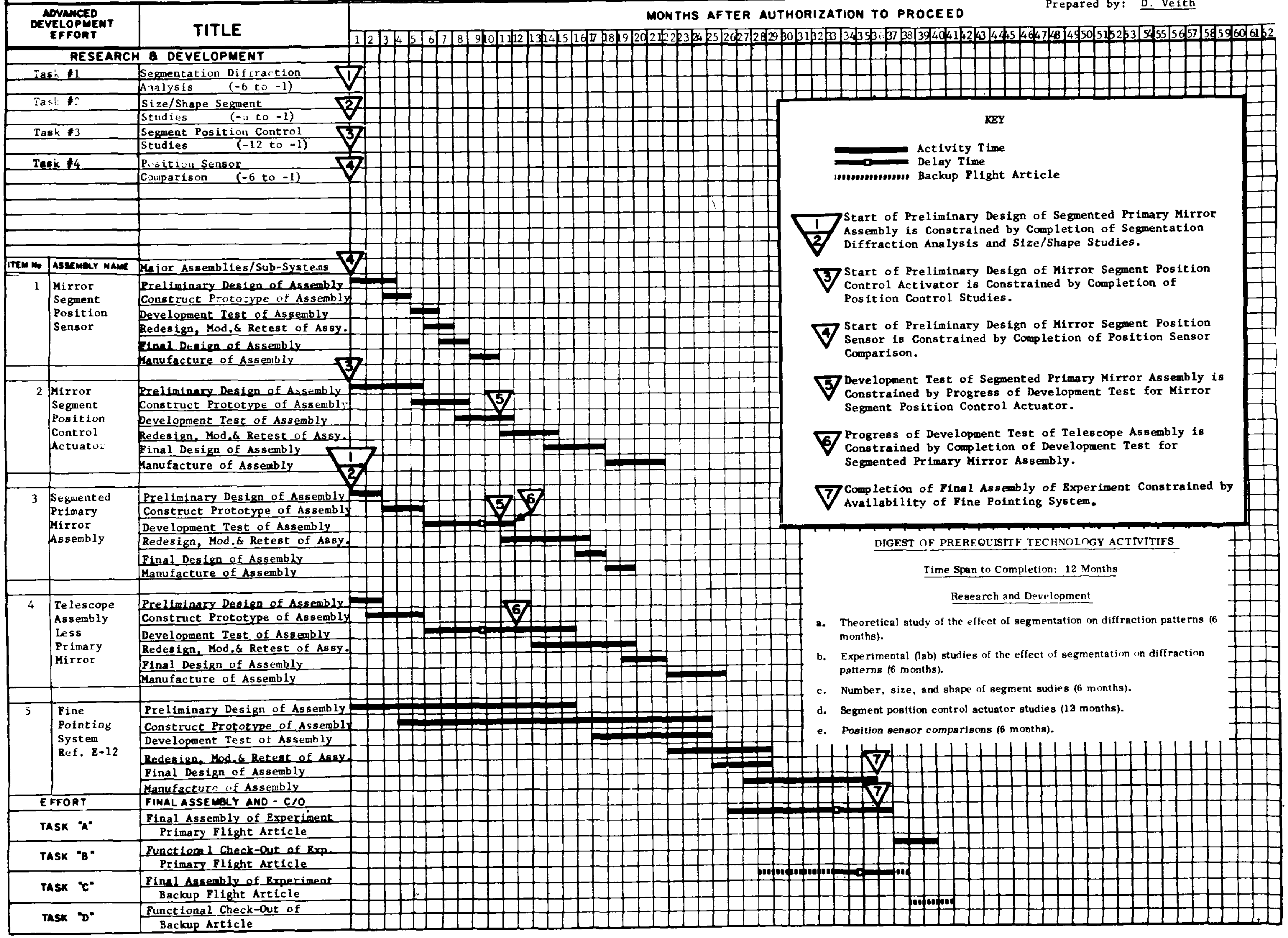
The experiment procedure is straightforward. The segmented mirror will be aligned, (the alignment procedure is a manned one using segment position actuators and sensors) pointed at the desired object and photographs made both of astronomical objects and of the figure test display. The photographs will be returned to earth and comparisons made with photographs obtained from a ground based segmented telescope.

PROJECT: OTAES PH I EXTENSION

LEGEND: SEGMENTED OPTICS
LEVEL OF DETAIL: EXPERIMENT PECULIAR MAJOR ASSEMBLIES/SUB-SYSTEMS
DETAILED ELSEWHERE: OTAES COMMON ASSEMBLIES/SUB-SYSTEMS

Figure IV-15

Detail Schedule E-15
Sheet 1 of 1
Date: 4 August 1966
Prepared by: D. Veith



V. DISCARDED EXPERIMENTS

Some space experiments were considered for OTAES and then discarded in the course of the study. The optical technology development implied by the experiments is necessary for space science and as such is included in the optical technology ground development program, but the final evaluation of the experiment did not require space testing.

The discarded experiments are:

1. Spectrograph Development.
2. Baffles Comparison.
3. Atmospheric Absorption Spectroscopy.
4. Photon-Photon Scattering.
5. Remote Manual Optical Alignment.
6. Visual Tracking Rating.
7. Cryogenic Cooling.
8. Photo-Electro-Optical Experiment (see Figure V-1).
9. Mirror Coating in Space.

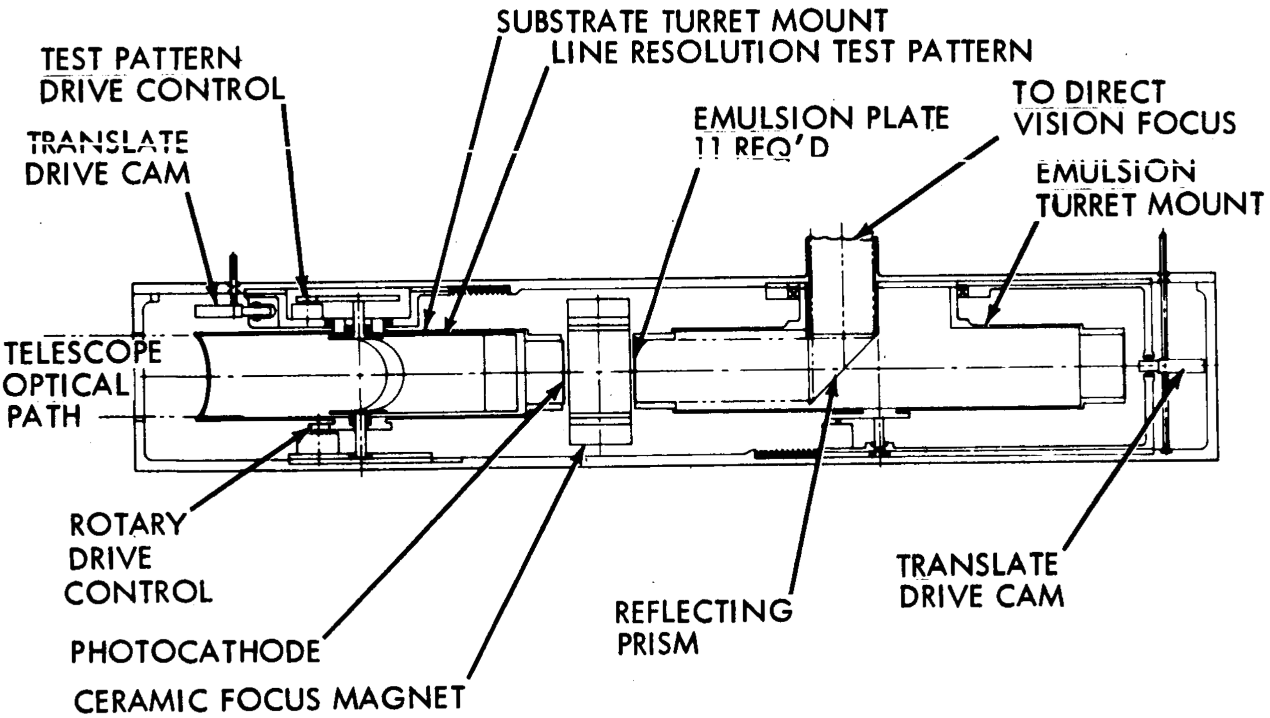


Figure V-1. Photo-Electro-Optical Experiment

VI. SYSTEMS INTEGRATION

The purpose of the Systems Integration effort of the OTAES study was to recommend integrated experiment configurations, preferred spacecraft configurations, and preferred missions. The basis of the OTAES Phase I Study was the development and justification of the individual experiments. Each experiment was analyzed to determine the equipment requirements, the criticality of astronaut participation, and the orbital requirements. Figure VI-1 summarizes the criticality of astronaut participation for each individual experiment. Given these requirements, the experiments were then integrated with the telescope configurations. This integration emphasized maximizing the probability of experiment success and obtaining a compatible time phasing.

In a parallel effort, several spacecraft concepts and missions were considered. As many as 20 spacecraft concepts and 9 mission profiles were developed. By evaluating the experiment requirements, these were narrowed down to four recommended missions and spacecraft which are discussed in the following paragraphs.

Integrated Experiment Configurations

The group of optical communications experiments was integrated with three telescopes. The 1.0-meter telescope, which has a 0.3-meter telescope rigidly mounted to it, is shown in figure VI-2. This pair of telescopes, which has one set of gimbals, contains equipment for the following experiments:

1. Optical Heterodyne Detection on Earth.
2. Optical Heterodyne Detection on the Spacecraft.
3. Communication with 10 Megahertz Bandwidth.
4. Direct Detection Optical Communication from Space to Ground.
5. 0.1 Arc/Second Tracking of a Ground Beacon.
6. Point-Ahead and Space-to-Ground-to-Space Loop Closure.
7. Transfer Tracking from One Ground Station to Another.
8. Pulse Distortion Measurements.
9. Atmospheric Measurements.

The third 0.3-meter laser telescope, which is separately gimballed, is shown in figure VI-3. This telescope supports the following experiments:

1. Optical Heterodyne Detection on Earth Backup.
2. Optical Heterodyne Detection on the Spacecraft.
3. Communication with 10 Megahertz Bandwidth.
4. Direct Detection Optical Communication from Space to Ground Backup.
5. 0.1 Arc/Second Tracking of a Ground Beacon Backup.
6. Point-Ahead and Space-to-Ground-to-Space Loop Closure Backup.
7. Transfer Tracking from One Ground Station to Another Backup.
8. Pulse Distortion Measurements.
9. Atmospheric Measurements.

Figure VI-4 illustrates the telescope which houses equipment for performance of the Isolation Comparison, Fine Guidance, and Stellar Interferometer experiments. The

EXPERIMENT \ HUMAN FUNCTION CLUSTER	PREPARATION & SET-UP	EXPERIMENT OPERATIONS	COMMUNICATION AND DATA MANAGEMENT	PREVENTIVE & REMEDIAL MAINTENANCE
Optical Heterodyne Detection on Earth	C	CD	C	C
Optical Heterodyne Detection on the Spacecraft	C	CD	C	C
Communication with 10 Megahertz Bandwidth	B	CD	B	C
Direct Detection from Space to Ground	B	CD	E	C
Precision Tracking of a Ground Beacon	C	CD	E	C
Point Ahead and Space-to-Ground-to-Space Loop Closure	C	CD	E	C
Transfer Tracking from One Ground Station to Another	C	CD	C	C
Phase Correlation Measurements	B	CD	C	C
Pulse Distortion Measurements	B	CD	C	C
Primary Mirror Figure Test and Correction	B	A	A	C
Thin Mirror Nesting Verification	A	BD	C	C
Fine Guidance	B	BD	C	C
Comparison of Isolation Techniques	B	B	B	C
Interferometer System	A	A	C	C
Segmented Optics	A	C	A	C

KEY: A = Man is essential.
B = Man is best, most efficient and/or hightly desirable.
C = Man can perform useful tasks.
D = Man could be undesirable.
E = Man is not involved.

Figure VI-1. Criticality of Man's Participation

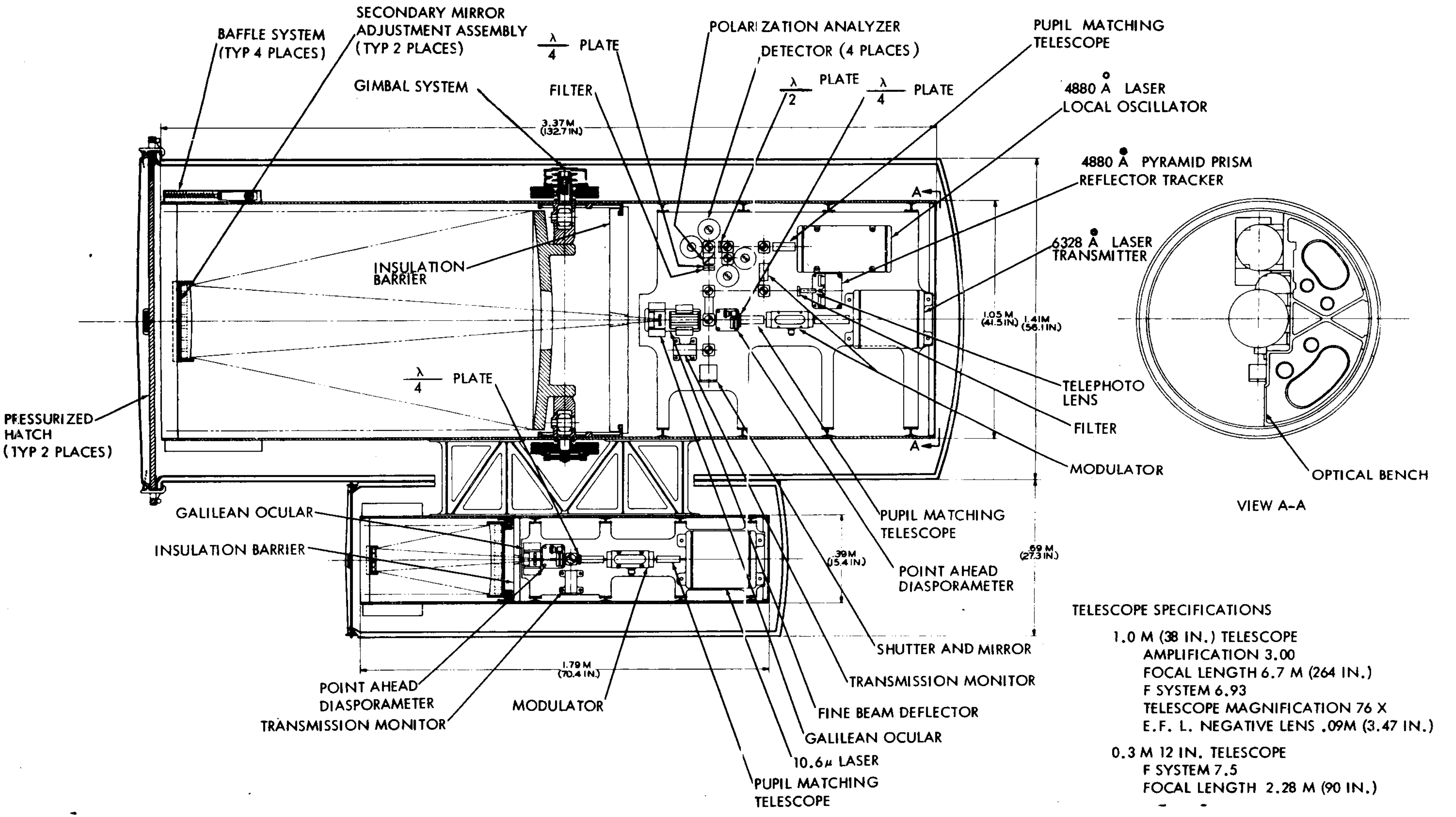


Figure VI-2. 1-Meter and 0.3-Meter Laser Telescope

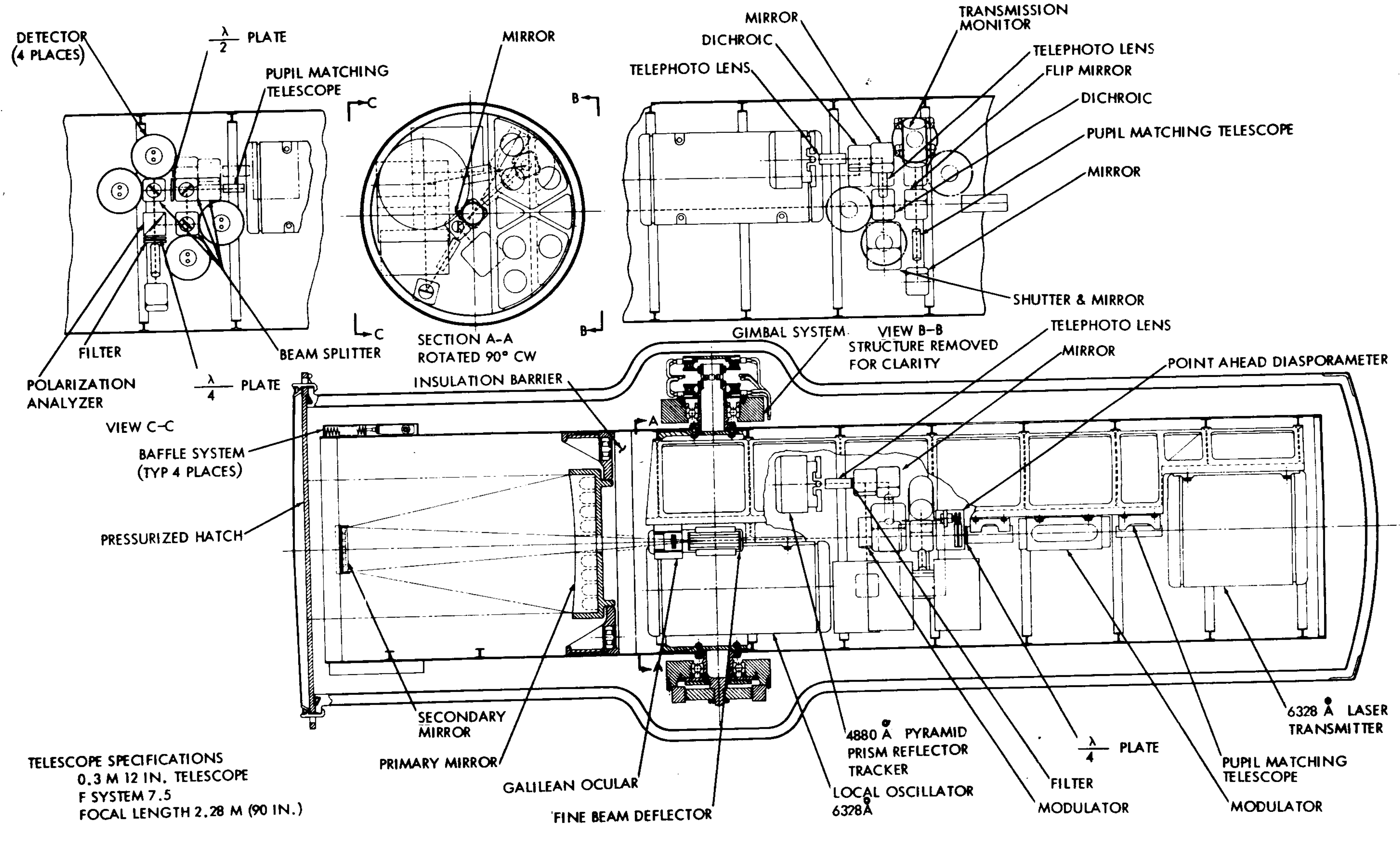


Figure VI-3. 0.3-Meter Gimballed Telescope

Segmented Optics experiment is also included in this package with its primary mirror co-linear but facing opposite the Fine Guidance primary mirror. This allowed for more efficient utilization of space and balanced gimbal equipment.

Figure VI-5 shows the non-gimballed experiment compartment which contains the Thin Mirror Nesting and Primary Mirror Figure Correction experiments. The commonality of equipment position and operating procedures allowed these two primary mirrors to be placed back to back. The resulting volume between the backs of the mirrors is appropriately used for this equipment.

Recommended Missions

The four most promising OTAES missions that have emerged from this study consist of either low earth or synchronous orbits mated with Saturn I or Saturn V launch vehicles. A brief outline of these missions follows:

Mission	Launch Vehicle Stack-up	Final Orbit	Spacecraft Configuration
I, Manned	S-IC/S-II/S-IVB/OTES/CSM	Synchronous	No. 1
III, Unmanned	S-IB/S-IVB/Centaur/OTES	Synchronous	No. 2
V, Manned	S-IB/S-IVB/OTES/CSM	Circular 649 km	No. 4
VI, Manned/ Unmanned	S-IC/S-II/S-IVB/OTES-1/ OTES-2/CSM	Synchronous Circular 649 km	No. 3-1 No. 3-2

All recommended experiments could be performed on Mission I. Mission III would only accomodate the nine optical communication, thin mirror, and mirror figure test experiments. Mission V would accomodate all others with the exception of the interferometer experiment.

However, it would be necessary to simplify the isolation comparison experiment for low earth orbits such as Mission V. The last recommendation, Mission VI, is a single-launch, dual mission in which one OTES spacecraft and the Apollo Command and Service Modules are left in low earth orbit while a second unmanned OTES spacecraft is placed into a synchronous orbit. The total combined experiments in Missions III and V could be performed in Mission VI.

A complete mission profile was developed for Mission I. This was instrumental in integrating the experiments into telescope configurations since the time phasing has considerable impact on the preferred number of telescopes. As a result, it was concluded that approximately 15. 5 days would be required for the manned portion of this mission. Figure VI-6 is a segment of the early portion of this mission showing the phasing and total time required to cycle through each experiment at least one time.

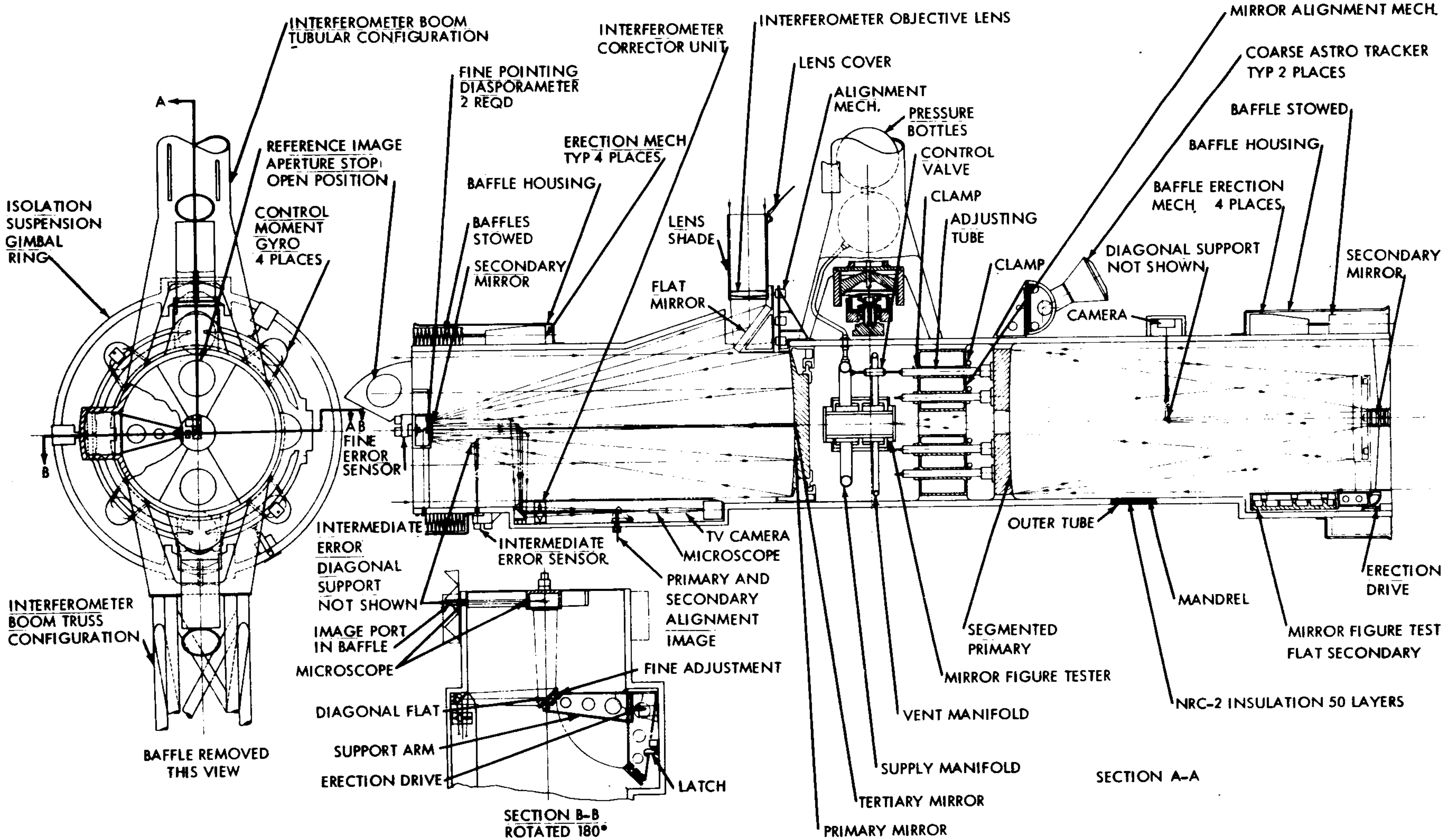


Figure VI-4. Fine Guidance, Segmented Optics, Isolation Comparison, and Stellar Interferometer Telescope

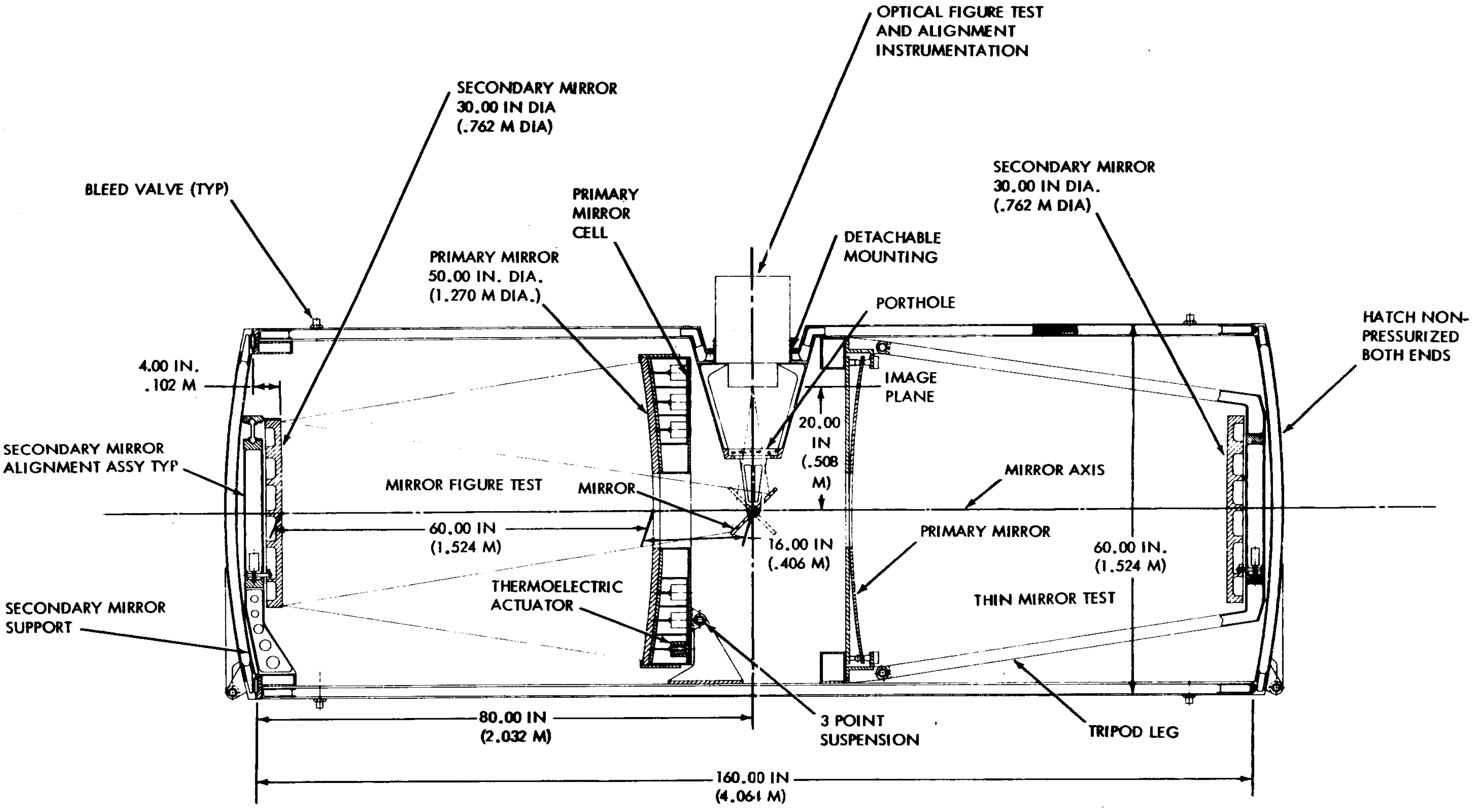


Figure VI-5. Primary Mirror Test Well

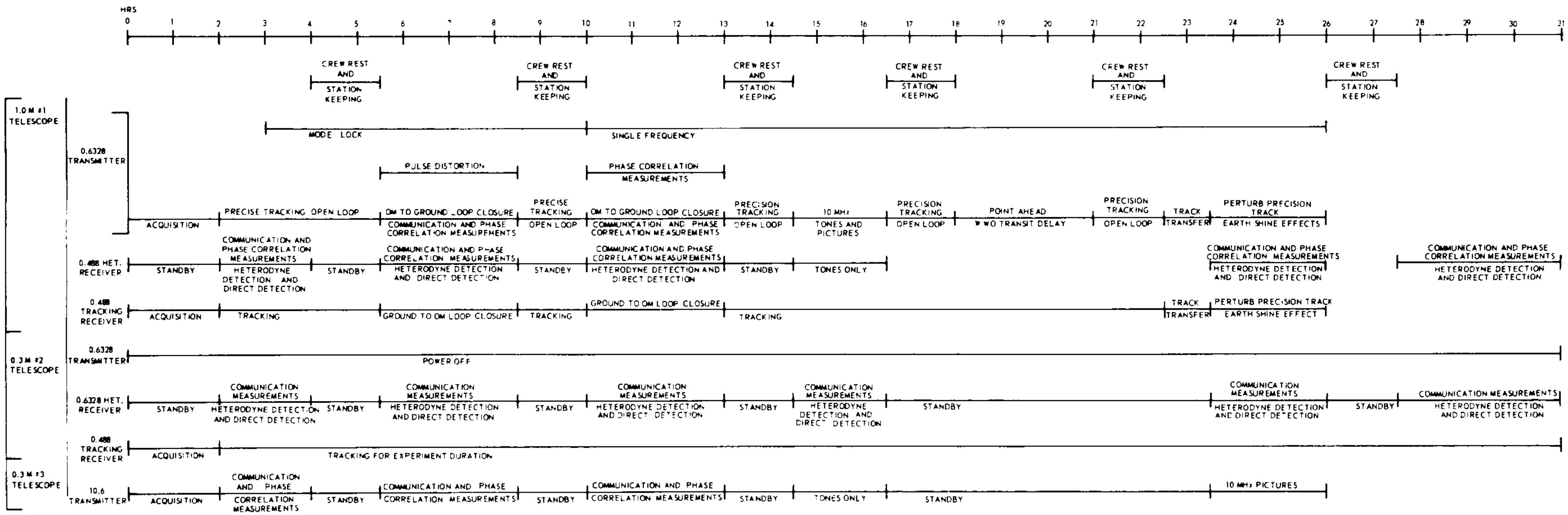


Figure VI-6. Time Line for Early Part of Mission

Recommended Spacecraft Concepts

Four recommended spacecraft configurations which contain integrated experiment groups were developed during this study. The telescope and experiment wells were conceptually designed in sufficient detail as a prerequisite to the spacecraft configuration development. The design flexibility of each spacecraft allows for substitution of wells and telescopes without degrading the overall mission concept. The following table lists the experiments included on the recommended configurations.

EXPERIMENT ON RECOMMENDED CONFIGURATIONS

OTAES Experiments	Spacecraft Configurations				
	1	2	3		4
			1	2	
Nine Laser Experiments	X	X	X		
Fine Guidance	X			X	X
Isolation Comparison	X			X	X
Segmented Optics	X			X	X
Interferometer	X				
Thin Mirror	X	X		X	X
Mirror Figure Test	X	X		X	X

Spacecraft configuration No. 1 (shown in figure VI-7) uses the basic LEM ascent stage. The telescopes and wells are located below with access to the shirtsleeve compartment between the wells by a new hatch in the LEM floor. The telescopes are oriented with their optical axis parallel to the LEM windows, which facilitates target acquisition. This group of experiments is designed for a synchronous orbit (Mission I).

Figure VI-8 shows spacecraft configuration No. 2 into which the Laser, Thin Mirror, and Mirror Figure Test experiments are integrated. This is the only spacecraft which is launched unmanned, although manning could be accomodated by providing for rendezvous and docking. In this case accessibility could be provided to the telescope wells.

Figure VI-9 depicts spacecraft configuration No. 3 which was developed for the dual mission (Mission VI). This configuration allows for the stellar oriented experiments to be conducted by one spacecraft in a 649 orbit and laser communication experiments by the other spacecraft in a synchronous orbit. The circular orbit spacecraft is unmanned.

Configuration No. 4 shown in figure VI-10 was developed for the stellar oriented experiment group for a 649 km orbit such as Mission V. A hatch in the LEM floor allows access to the experiment equipment. The telescope contains the Fine Guidance, Isolation Comparison, and Segmented Optics experiments. The Thin Mirror and Mirror Figure Test experiments are also included in this spacecraft.

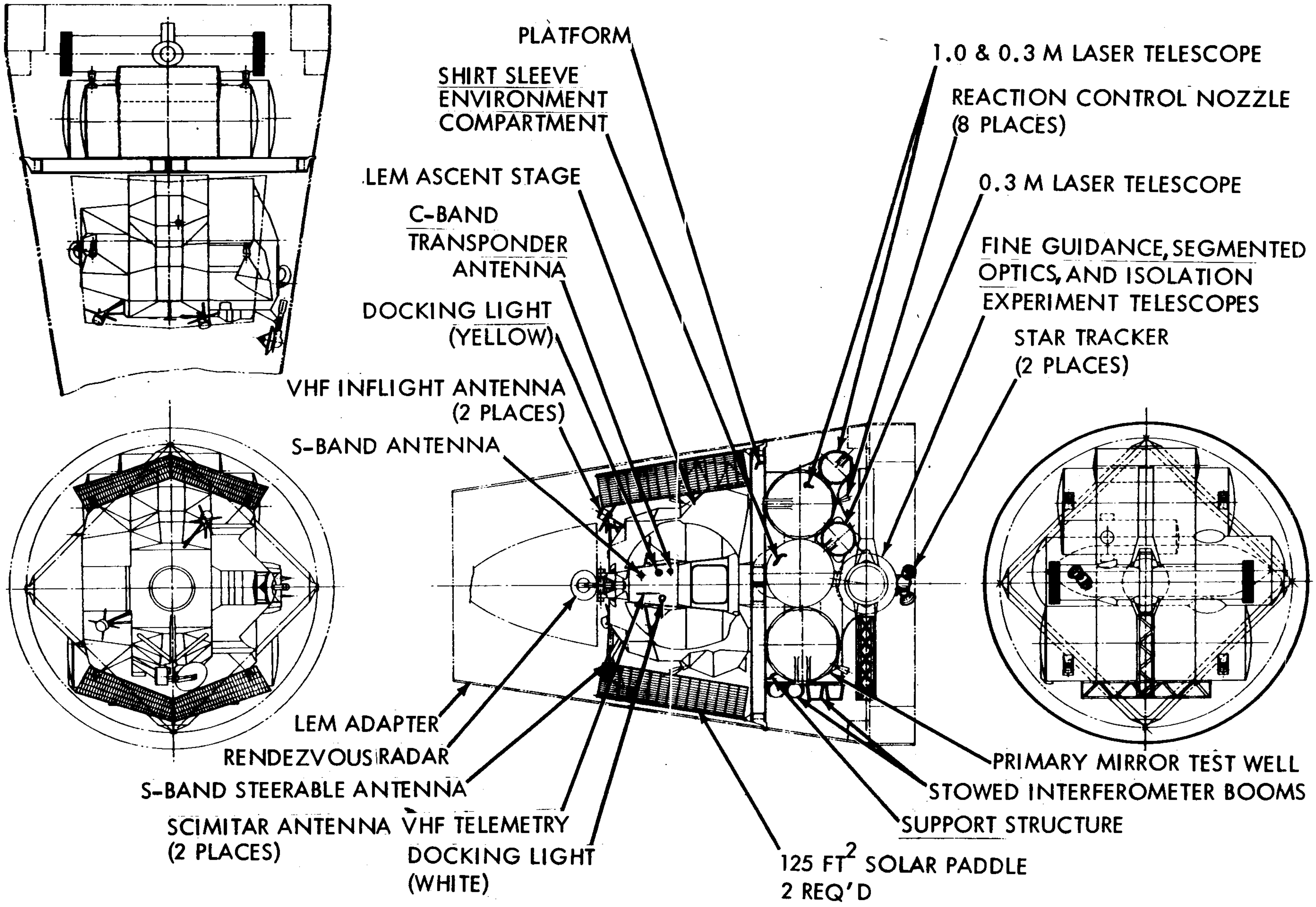


Figure VI-7. Spacecraft Configuration No. 1

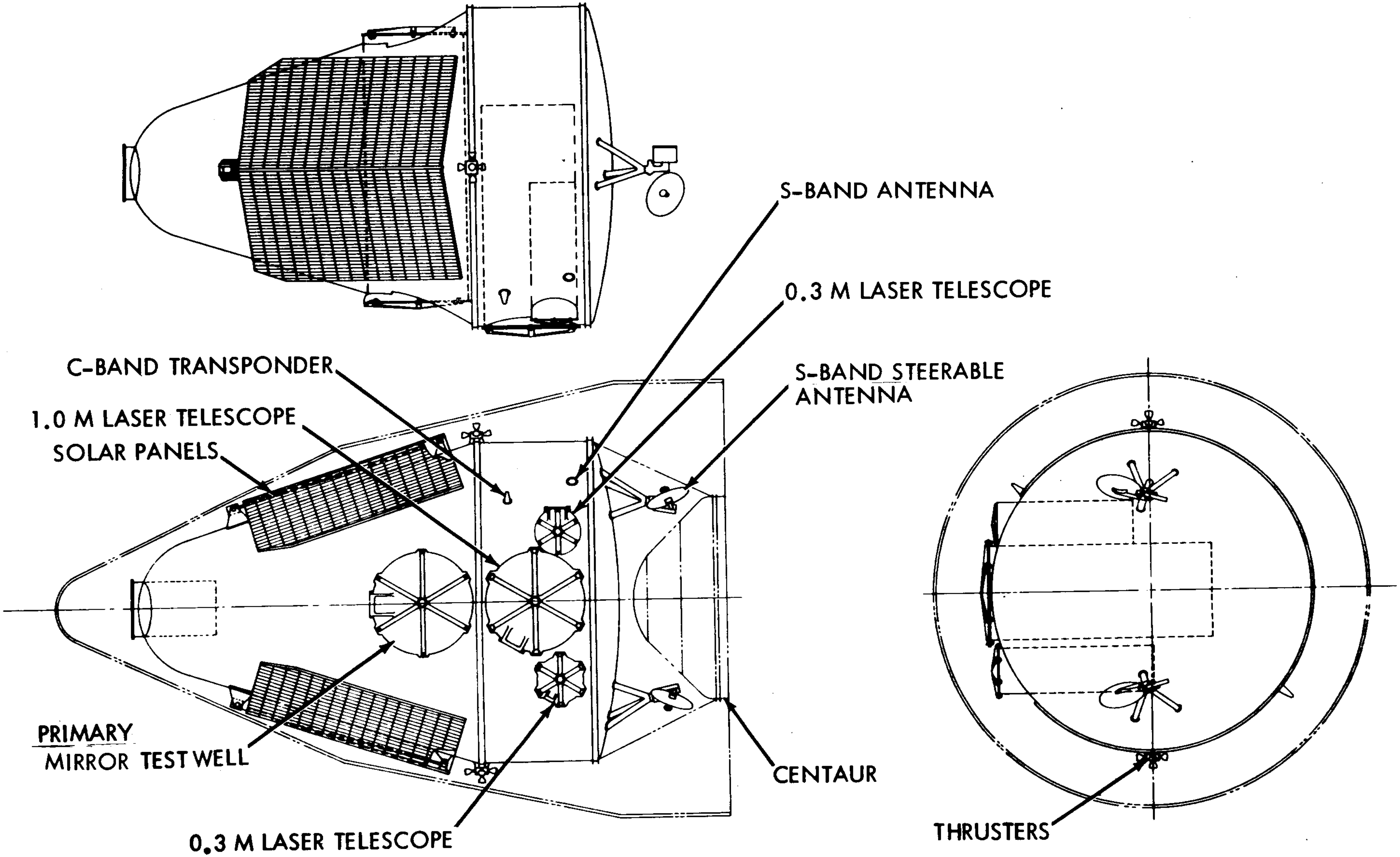


Figure VI-8. Spacecraft Configuration No. 2

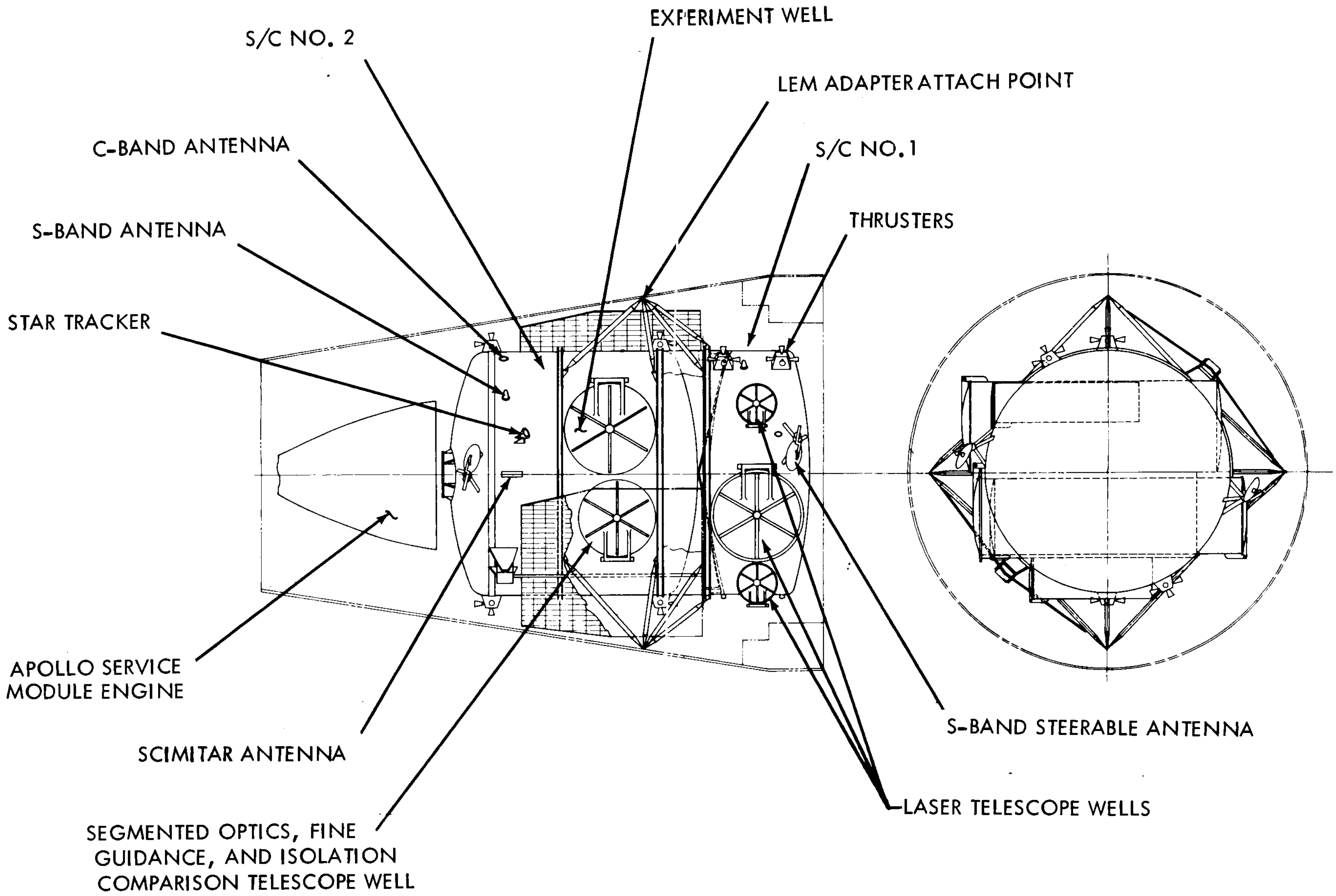


Figure VI-9. Spacecraft Configuration No. 3

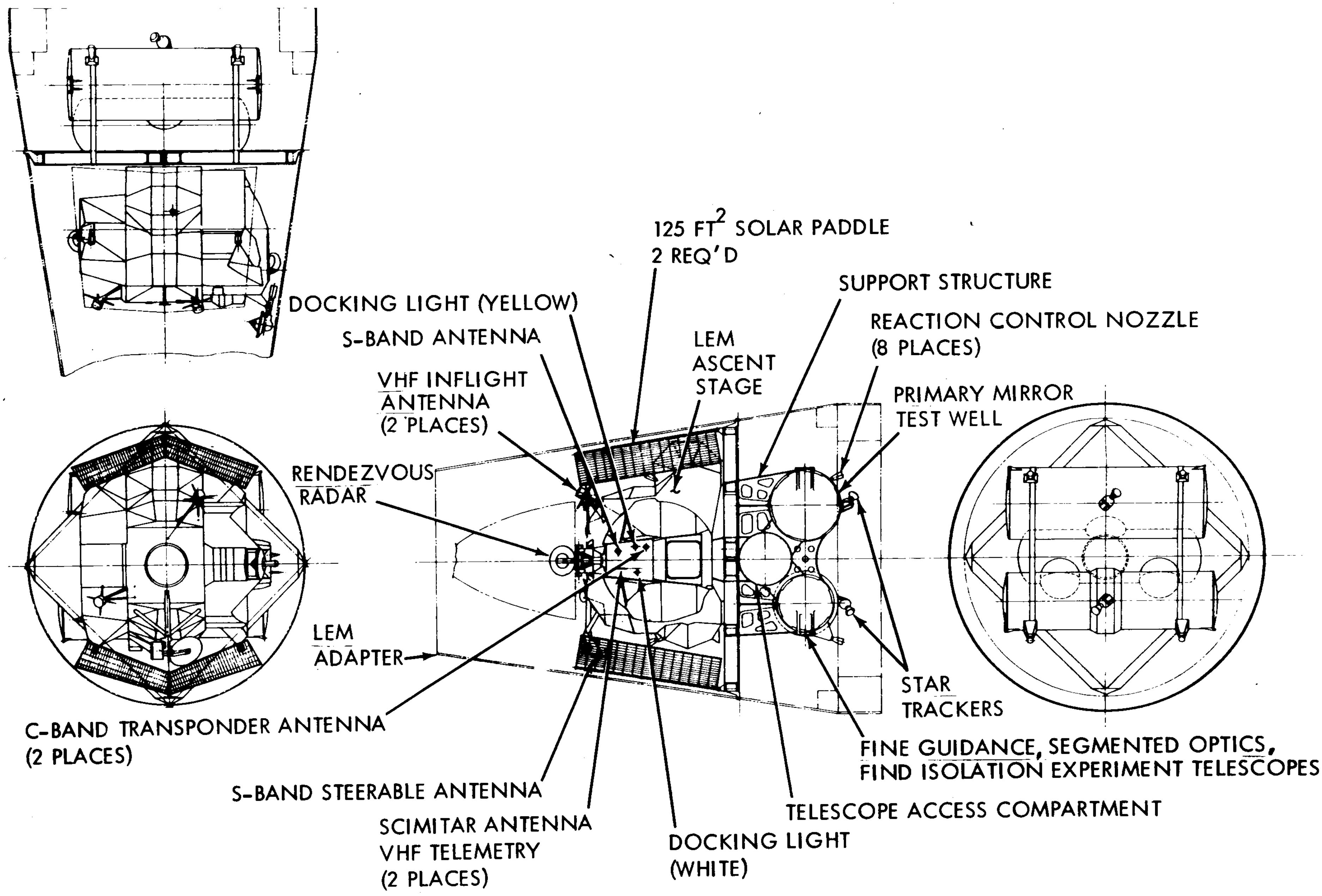


Figure VI-10. Spacecraft Configuration No. 4

VII. OTAES MASTER PLANNING SCHEDULE

An OTAES Master Plan Schedule was developed which integrated the experiments into experiment groups and these in turn into spacecraft and launch vehicle alternatives. While this Master Plan gives an overall visibility of the time sequenced requirements of a total OTAES program, it also provides an understanding of implementation alternatives as dictated by experiment alternatives. Throughout the master planning analysis, the philosophy maintained has been that the individual experiments rather than spacecraft have dictated the integration times. This ensures that the specific experiment technological advances are not subordinated to other integration factors.

The experiment candidate groups have been determined primarily by technical commonality and other experiment imposed requirements such as orbits and astronaut participation. The resultant candidate groups are:

1. Group A, All recommended experiments.
2. Group B, Nine laser experiments.
3. Group C, Fine guidance, isolation comparison, thin mirror, mirror figure control, and segmented optics experiments.

Figure VII-1 indicates the availability of each candidate group collectively and determines the earliest date for group integration into a spacecraft. The additional time beyond individual experiment availability results from incorporating the necessary activities such as experiments:

(a) Packaging;
(b) Shipment;
(c) Receiving and Inspection; and
(d) Pre-installation acceptance activities.

For this study four candidate missions have been chosen which utilize the three candidate groups most efficiently. The candidate missions are:

	Approach	Type of Orbit	Spacecraft	Experiment Group Utilized
(a)	I	Synchronous	Manned	Group A
(b)	II	Synchronous	Unmanned	Group B
(c)	III (Dual)	Synchronous	Unmanned	Group B
		Low Earth	Manned	Group C
(d)	IV	Low Earth	Manned	Group C

Figures VII-2 (a), (b), (c), and (d) give the Master Plan schedules for each of these approach alternatives.

PROJECT: OTAES PH. I EXTENSION

LEGEND: OPTICAL TECHNOLOGY APOLLO EXTENSION SYSTEM MASTER PLANNING SCHEDULE

Figure VII-1

Date: 18 August 1966

MASTER SCHED. ITEM	DETAIL SCHED. REFERENCE	TITLE	MONTHS AFTER AUTHORIZATION TO PROCEED (1–62)
2.0		Experiment Candidate Grouping	
2.1		Candidate Group "A"	
2.1.1	1.1.3	Pkg,Ship,Rec.& PIA Exp. #E-1	
2.1.2	1.2.3	Pkg.,Ship, Rec.& PIA Exp. #E-2	
2.1.3	1.3.3	Pkg.,Ship, Rec.& PIA Exp. #E-3	
2.1.4	1.4.3	Pkg.,Ship, Rec.& PIA Exp. #E-4	
2.1.5	1.5.3	Pkg.,Ship, Rec.& PIA Exp. #E-5	
2.1.6	1.6.3	Pkg.,Ship, Rec.& PIA Exp. #E-6	
2.1.7	1.7.3	Pkg.,Ship, Rec.& PIA Exp. #E-7	
2.1.8	1.8.3	Pkg.,Ship, Rec.& PIA Exp. #E-8	
2.1.9	1.9.3	Pkg.,Ship, Rec.& PIA Exp. #E-9	
2.1.10	1.10.3	Pkg.,Ship, Rec.& PIA Exp. #E-10	
2.1.11	1.11.3	Pkg.,Ship, Rec.& PIA Exp. #E-11	
2.1.12	1.12.3	Pkg.,Ship, Rec.& PIA Exp. #E-12	
2.1.13	1.13.3	Pkg.,Ship, Rec.& PIA Exp. #E-13	
2.1.14	1.14.3	Pkg.,Ship, Rec.& PIA Exp. #E-14	
2.1.15	1.1 .3	Pkg.,Ship, Rec.& PIA Exp. #E-15	
2.1.16	1.17.3	Del. Exp.Group "A" to Integration	(To Integration Area)
2.2		Candidate Group "B"	
2.2.1	1.1.3	Pkg.,Ship, Rec.& PIA Exp.#E-1	
2.2.2	1.2.3	Pkg.,Ship,Rec.& PIA Exp. #E-2	
2.2.3	1.3.3	Pkg.,Ship,Rec.& PIA Exp. #E-3	
2.2.4	1.4.3	Pkg.,Ship,Rec.& PIA Exp. #E-4	
2.2.5	1.5.3	Pkg.,Ship,Rec.& PIA Exp. #E-5	
2.2.6	1.6.3	Pkg.,Ship,Rec.& PIA Exp. #E-6	
2.2.7	1.7.3	Pkg.,Ship,Rec.& PIA Exp. #E-7	
2.2.8	1.8.3	Pkg.,Ship,Rec.& PIA Exp. #E-8	
2.2.9	1.9.3	Pkg.,Ship,Rec.& PIA Exp. #E-9	
2.2.10		Del.Exp.Group "B" to Integration	(To Integration Area)
2.3		Candidate Group "C"	
2.3.1	1.10.3	Pkg.,Ship,Rec.& PIA Exp. #E-10	
2.3.2	1.11.3	Pkg.,Ship,Rec.& PIA Exp. #E-11	
2.3.3	1.12.3	Pkg.,Ship,Rec.& PIA Exp. #E-12	
2.3.4	1.13.3	Pkg.,Ship,Rec.& PIA Exp. #E-13	
2.3.5	1.15.3	Pkg.,Ship,Rec.& PIA Exp. #E-15	
2.3.6		Del. Exp. Group "C" to Integration	(To Integration Area)

PROJECT: OTAES PH. I EXTENSION

LEGEND: OPTICAL TECHNOLOGY APOLLO EXTENSION SYSTEM MASTER PLANNING SCHEDULE

Figure VII-2(a)

Date: 11 August 1966

MASTER SCHED. ITEM	DETAIL SCHED. REFERENCE	TITLE	MONTHS AFTER AUTHORIZATION TO PROCEED
3.0		OTAES STUDY (NASA PH. "A")	
3.1	NAS8-20256	PHASE I	(-14 to -10)
3.2	NAS8-20256	PHASE I EXTENSION	(-9 to -5)
3.3		PHASE II	(-5 to -1)
4.0	3.1	BASIC OTAES	
4.1	3.1	Preliminary Design (NASA Ph. "B")	
4.2	3.1	Detail Design & Dev. (NASA Ph. "C")	
4.3	3.1	Manufacture (NASA Ph. "D")	
4.3.1	3.1	Facilities, Tool & Plan	
4.3.2	3.1	Fab., Assemble, Install & Mod.	
4.3.2.1	3.1	Approach I & II	
4.3.2.1.1	3.1	Final Articles #1 & 2 (Qual Tests)	
4.3.2.1.2	3.1	Flight Article #3 (Boilerplate)	
4.3.2.1.3	3.1	Flight Article #4 (Fully Operational)	
4.3.2.1.4	3.1	Flight Article #5 (Backup)	
4.3.2.2		Approach III	
4.3.2.2.1	3.1	Final Articles #1 & 2 (Qual Tests)	
4.3.2.2.2	3.1	Flight Article #3 (Boilerplate)	
4.3.2.2.3	3.1	Flight Article #4 (Fully Operational)	
4.3.2.2.4	3.1	Flight Article #5 (Backup)	
4.3.2.2.5	3.1	Final Article #6 (Qual. Test)	
4.3.2.2.6	3.1	Flight Article #7 (Fully Operational)	
4.3.2.2.7	3.1	Flight Article #8 (Backup)	
4.3.2.3		Approach IV	
4.3.2.3.1	3.1	Final Articles #1 & 2 (Qual Tests)	
4.3.2.3.2	3.1	Flight Article #3 (Boilerplate)	
4.3.2.3.3	3.1	Flight Article #4 (Fully Operational)	
4.3.2.3.4	3.1	Flight Article #5 (Backup)	

PROJECT: OTAES PH. I EXTENSION

LEGEND: OPTICAL TECHNOLOGY APOLLO EXTENSION SYSTEM MASTER PLANNING SCHEDULE

Figure VII-2(b)

Date: 10 August 1966

MONTHS AFTER AUTHORIZATION TO PROCEED

1 2 3 4 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83

MASTER SCHED. ITEM	DETAIL SCHED. REFERENCE	TITLE	Schedule
5.0		Integration & System Check-Out	
5.1		Approach I	
5.1.1	4.3.2.1.1	Final Article #1 w/Exp.Dummies	(Del to Structural Test)
5.1.2	4.3.2.1.1	Flight Article #2 w/Exp.Gp."A"(Prototypes)	(Del. to Environmental Test)
5.1.3	4.3.2.1.2	Flight Article #3 w/Exp.Gp."A"(Boiler Plate)	(Ship to KSC)
5.1.4	4.3.2.1.3/ 2.1.17	Flight Article #4 w/Exp.Gp."A"(Primary)	(Ship to KSC)
5.1.5	4.3.2.1.4	Flight Article #5 w/Exp.Gp."A"(Back-Up)	(Ship to KSC)
5.2		Approach II	
5.2.1	4.3.2.1.1	Final Article #1 w/Exp. Dummies	(Del. to Structural Test)
5.2.2	4.3.2.1.1	Flight Article #2 w/Exp.Gp. "B"(Prototypes)	(Del. to Environmental Test)
5.2.3	4.3.2.1.2	Flight Article #3 w/Exp.Gp."B"(Boilerplate)	(Ship to KSC)
5.2.4	4.3.2.1.3/ 2.2.10	Flight Article #4 w/Exp.Gp."B"(Primary)	(Ship to KSC)
5.2.5	4.3.2.1.4	Flight Article #5 w/Exp.Gp."B"(Back-Up)	(Ship to KSC)
5.3		Approach III	
5.3.1	4.3.2.2.1	Final Article #1 w/Exp. Dummies	(Del. to Structural Test)
5.3.2	4.3.2.2.1	Flight Article #2 w/Exp.Gp."C"(Prototype)	(Del. to Environmental Test)
5.3.3	4.3.2.2.2	Flight Article #3 w/Exp.Gp."C"(Boilerplate)	(Ship to KSC)
5.3.4	4.3.2.2.3/ 2.3.7	Flight Article #4 w/Exp.Gp."C"(Primary)	(Ship to KSC)
5.3.5	4.3.2.2.4	Flight Article #5 w/Exp.Gp."C"(Backup)	(Ship to KSC)
5.3.6	4.3.2.2.5	Flight Article #6 w/Exp.Gp."B"(Prototype)	(Del. to Environmental Test)
5.3.7	4.3.2.2.6/ 2.3.10	Flight Article #7 w/Exp.Gp."B"(Primary)	(Ship to KSC)
5.3.8	4.3.2.2.7	Flight Article #8 w/Exp.Gp."B"(Back-Up)	(Ship to KSC)
5.4		Approach IV	
5.4.1	4.3.2.3.1	Final Article #1 w/Exp.Dummies	(Del. to Structural Test)
5.4.2	4.3.2.3.1	Flight Article #2 w/Exp.Gp."C"(Prototypes)	(Del. to Environmental Test)
5.4.3	4.3.2.3.2	Flight Article #3 w/Exp.Gp."C"(Boilerplate)	(Ship to KSC)
5.4.4	4.3.2.3.3/ 2.3.7	Flight Article #4 w/Exp.Gp."C"(Primary)	(Ship to KSC)
5.4.5	4.3.2.3.4	Flight Article #5 w/Exp.Gp."C"(Backup)	(Ship to KSC)

KEY

Primary Flight Article

Backup Flight Article

PROJECT: OTAES PH. I EXTENSION

LEGEND: OPTICAL TECHNOLOGY APOLLO EXTENSION SYSTEM
MASTER PLANNING SCHEDULE

Figure VII-2(c)

Date: 10 August 1966

MASTER SCHED. ITEM	DETAIL SCHED. REFERENCE	TITLE	MONTHS AFTER AUTHORIZATION TO PROCEED (1–62)
6.0		Environmental Testing	
6.1		Approach I	
6.1.1		Structural Test Model	
6.1.1.1	5.1.1	Instrument & Test	F/A #1
6.1.1.2		Redesign, Mod.& Retest	
6.1.2		OTAES-A Prototype	
6.1.2.1	5.1.2	Instrument & Test	F/A #2
6.1.2.2		Redesign, Mod.& Retest	
6.2		Approach II	
6.2.1		Structural Test Model	
6.2.1.1	5.2.1	Instrument & Test	F/A #1
6.2.1.2		Redesign, Mod. & Retest	
6.2.2		OTAES-B Prototype	
6.2.2.1	5.2.2	Instrument & Test	F/A #2
6.2.2.2		Redesign, Mod. & Retest	
6.3		Approach III	
6.3.1		Structural Test Model	
6.3.1.1	5.3.1	Instrument & Test	F/A #1
6.3.1.2		Redesign, Mod. & Retest	
6.3.2		OTAES-B Prototype	
6.3.2.1	5.3.6	Instrument & Test	F/A #6
6.3.2.2		Redesign, Mod. & Retest	
6.3.3		OTAES-C Prototype	
6.3.3.1	5.3.2	Instrument & Test	F/A #2
6.3.3.2		Redesign, Mod. & Retest	
6.4		Approach IV	
6.4.1		Structural Test Model	
6.4.1.1	5.4.1	Instrument & Test	F/A #1
6.4.1.2		Redesign, Mod. & Retest	
6.4.2		OTAES-C Prototype	
6.4.2.1	5.4.2	Instrument & Test	F/A #2
6.4.2.2		Redesign, Mod. & Retest	

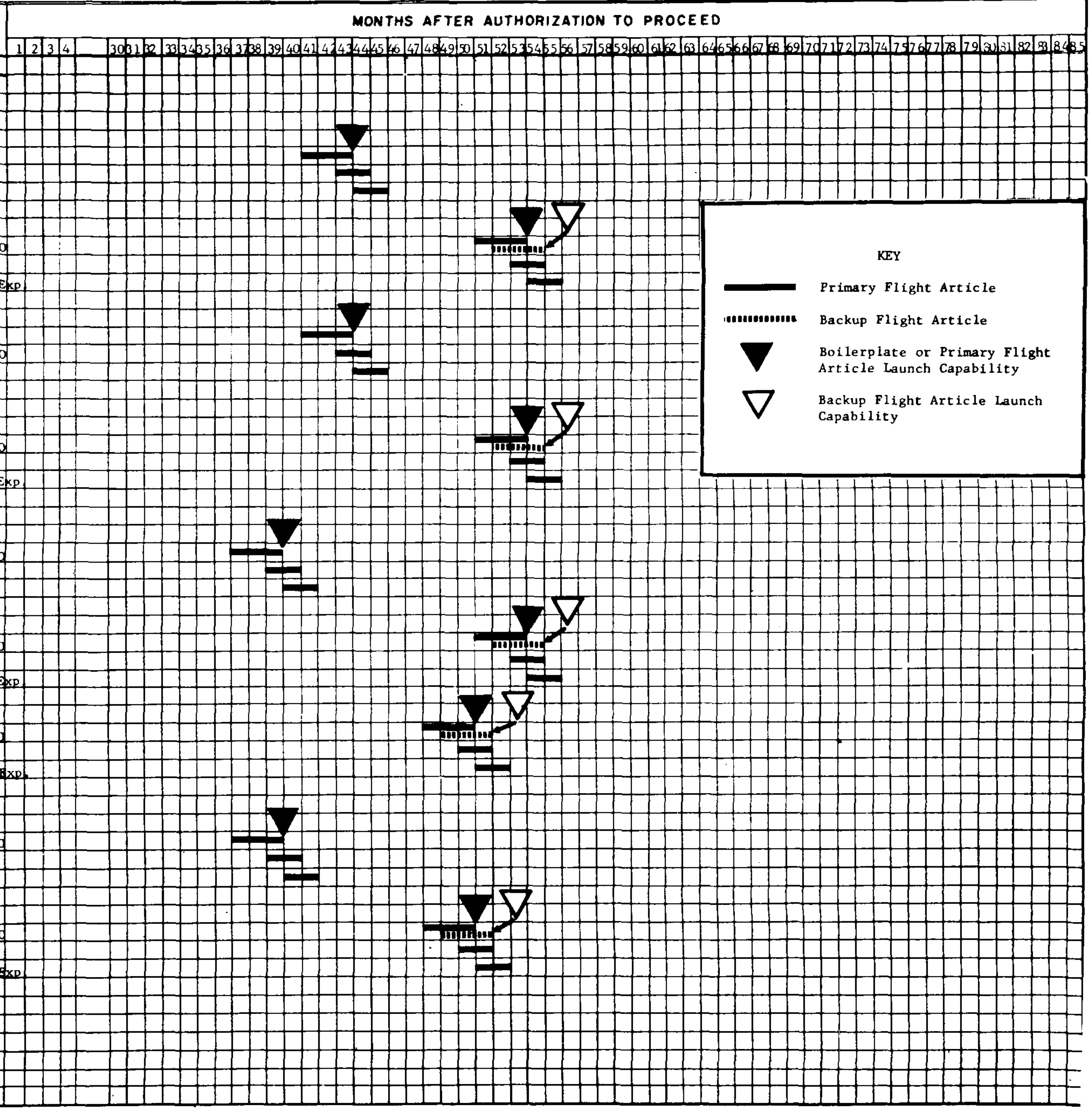
PROJECT: OTAES PH. I EXTENSION

LEGEND: OPTICAL TECHNOLOGY APOLLO EXTENSION SYSTEM MASTER PLANNING SCHEDULE

Figure VII-2(d)

Date: 24 August 1966

MASTER SCHED. ITEM	DETAIL SCHED. REFERENCE	TITLE
7.0		PRE-LAUNCH CHECK-OUT & MISSION SUPPORT
7.1		Approach I
7.1.1		Boiler Plate Mission
7.1.1.1	5.1.3	Experiments & Launch Sys. C/O
7.1.1.2		Range & Mission Support
7.1.1.3		Mission Support for B/P Exp.
7.1.2		OTAES-A Mission
7.1.2.1	5.1.4/5.1.5	Experiments & Launch Sys. C/O
7.1.2.2		Range & Mission Support C/O
7.1.2.3		Mission Support for OTAES-A Exp.
7.2		Approach II
7.2.1		Boiler Plate Mission
7.2.1.1	5.2.3	Experiments & Launch Sys. C/O
7.2.1.2		Range & Mission Support
7.2.1.3		Mission Support for B/P Exp.
7.2.2		OTAES-B Mission
7.2.2.1	5.2.4/5.2.5	Experiments & Launch Sys. C/O
7.2.2.2		Range & Mission Support C/O
7.2.2.3		Mission Support for OTAES-B Exp.
7.3		Approach III
7.3.1	5.3.3	Boiler Plate Mission
7.3.1.1		Experiments & Launch Sys. C/O
7.3.1.2		Range & Mission Support C/O
7.3.1.3		Mission Support for B/P Exp.
7.3.2		OTAES-B Mission
7.3.2.1	5.3.7/5.3.8	Experiments & Launch Sys. C/O
7.3.2.2		Range & Mission Support
7.3.2.3		Mission Support for OTAES-B Exp.
7.3.3		OTAES-C Mission
7.3.3.1	5.3.4/5.3.5	Experiments & Launch Sys. C/O
7.3.3.2		Range & Mission Support
7.3.3.3		Mission Support for OTAES-C Exp.
7.4		Approach IV
7.4.1		Boiler Plate Mission
7.4.1.1	5.4.3	Experiments & Launch Sys. C/O
7.4.1.2		Range & Mission Support
7.4.1.3		Mission Support for B/P Exp.
7.4.2		OTAES-C Mission
7.4.2.1	5.4.4/5.4.5	Experiments & Launch Sys. C/O
7.4.2.2		Range & Mission Support
7.4.2.3		Mission Support for OTAES-C Exp.



VIII. CONCLUSIONS AND RECOMMENDATIONS

As a result of the OTAES Phase I study, a number of conclusions have been reached which are worthy of being set forth here even though the study is not yet complete, since nothing in the projected work during Part II is at all likely to reverse or significantly modify these findings. Based on these conclusions, a number of recommendations are appended. For brevity, these conclusions and recommendations have been collected together and set forth here without the background discussion and supporting reasoning which are contained elsewhere in the Part I Final Report.

Conclusions

1. Substantial advances in many areas of optical technology are required by NASA in performance of its future space missions.

   This is true for most of the NASA programs now being funded in the scientific literature.

2. Needed optical technology exhibits commonality of application.

   There is a broad commonality of the optical technology needs for astronomy, for remote sensing of the earth, for meteorology, for planetary observation, and for space optical communications. The specific technology developments required in components and subsystems have so much in common that any effort to separate the pieces or fragment the programs will inevitably result in increased cost and reduced performance. That is, there is a commonality of application.

3. Application commonality strongly favors an integrated development program.

   If each of the special scientific and governmant groups having responsibility for individual applications were to individually develop the technology required for their particular interest, the resulting programs would overlap and no single one could be as effective in timely development of reliable and economic space optical equipment for the broad applications envisioned. Moreover, there is optical equipment which would be desirable to more than one of these special interests but whose development could not be justified for one application alone. Therefore, consideration of the technology from the standpoint of its application leads to the conclusion that a single technology development program must be instituted and sustained.

4. The needed optical technology exhibits commonality of space experiment programs.

   As a result of matching the OTAES experiments with the problem areas, it is clear that a great deal of interdependence of the experiments exists and that simultaneous performance of the experiments is mandatory to use fully the experimental equipment, measurements, missions, and results. Therefore, for that optical technology which requires space testing for its development, significant advantages are gained by flying the experiments in groups even though each of them could be flown singly. In fact, as discussed in the technical conclusions, nine of the recommended experiments require identically the same equipment for their performance.

5. This experiment commonality impels a single integrated development program.

Thus, in two areas, commonality of technology to applications and commonality of the technology development programs, it is concluded that a single development program rather than several fragmented efforts is advantageous.

6. Some optical technology which should now be in planning is not covered by OTAES.

The OTAES contracts are limited to consideration of the technology which leads to space testing. Increased emphasis by NASA is needed to develop an orderly program for developing the optical technology not covered by the present OTAES contracts. A comprehensive, orderly program for optical technology should include in proper perspective both that part which leads to space testing and that part which does not. The ultimate responsibility for this planning, of course, rests with NASA, but is so intimate to the OTAES technology planning as to require participation by the OTAES Contractor. The additional ground development is beyond the scope of work of the existing contract but should procede simultaneously with the OTAES study.

Technical Conclusions

7. Of the 36 experiments considered during the OTAES study, to date 15 are now believed to be prime candidates for flight experiments. These 15 all contribute toward needed technology; all require testing in space; and all are deemed feasible.

8. Although the experiments can be flown single, technological data will be significantly increased and commonality economies maximized by launching the experiments in groups.

9. To adequately develop integrated groupings of OTAES experiments and to fully explore experiment feasibility, it has been necessary to generate a sufficient level of conceptual detail in the areas of the experiment, the experiment supporting systems, the environment, and the mission. Such effort has identified additechnological problems effecting the experiment and its relationship to the spacecraft configuration, the supporting (experiment) spacecraft subsystems, the environment, and the mission constraints.

10. All of the experiments recommended in this study could be performed on a synchronous manned mission. Alternatively, all experiments except one, Interferometer Development, could be performed on a combination low earth orbit manned mission and a synchronous unmanned mission.

11. All of the recommended experiments can be accomplished with Apollo hardware including the Command and Service Modules and the LEM Ascent Stage. Alternates to the Ascent Stage offer some advantages and are still under consideration. Configurations requiring major development are not necessary for the OTAES program.

12. Modifications to the Command and Service Modules and the LEM Ascent Stage will be necessary in order to accomplish the manned synchronous mission.

13. A total of 15.5 days are required on the manned synchronous mission to perform all of the recommended experiments at least once.

14. Synchronous orbit may require electrical heating to prevent freezing in the ECS radiators and RCS valves. This problem will not occur in low earth orbit since Earth albedo will be sufficient to keep these components at operating temperatures.

15. Twenty-four hour elliptical orbits have been discarded due to high radiation dosages. This applies to both manned and unmanned missions.

16. Within certain constraints a synchronous orbit coupled with the judicious choice of ground station configuration permits all of the experiments to be performed on a single ground station complex which would include terminal for point-ahead and tracking transfer experiments.

17. For the laser communication point-ahead and station transfer experiments it is desirable that the angle between the lines of sight from the spacecraft to the two ground terminals should remain nearly constant, a condition which requires low inclination synchronous orbits.

18. Although several of the OTAES laser experiments will result in video bandwidth data, judicious application of data compression and non-real-time technique will permit adaptation to the DSIF telemetry capability planned for the 1970-75 time period.

19. For any of the recommended experiments only minor modification of existing facilities is required to implement up-link commands to the spacecraft for either manned or unmanned operations.

20. If for any reason it is desirable to utilize RF and optical ground station facilities which are separated geographically from each other, they should not be more than a few hundred miles apart.

21. The nine recommended laser experiments should be performed as a single group since the performance of one implies the need for equipment to perform the others.

22. Optical measurement of the random variations in the atmospheric index of refraction are needed. Present knowledge of these effects is largely extrapolated, through correlation or structure function, from microwave measurements. The few

available measurements at optical frequencies have been made with stellar or thermal sources. Such data are inadequate for the design of coherent laser instrumentation.

23. Optical coherent scaling laws are not well established. To assess the frequencies dependence, at least two widely separated space-to-earth transmitter wavelengths are desirable. In recent years, the HeNe (0.6328 micron) components have reached an advances state of development, offering high reliability. The N_2-CO_2 (10.6 micron) laser is a new form having high power in efficiency and favorable wavelengths for operation in the atmosphere. Hence, these two frequencies offer both adequate frequency separation for the purpose of atmospheric measurement and showing great promise for certain operational applications.

24. The laser telescope should be mounted in mechanical gimbals to give ±1 degree angular freedom in pitch and yaw. Roll control should be provided by the spacecraft attitude control system.

25. The spacecraft attitude control system should be designed to limit the peak excursion of the spacecraft to ±6 arc minutes.

26. Spacecraft attitude stability should be provided by control moment gyros, with reaction jets for periodic dumping of accumulated angular momentum.

27. The fine guidance telescope should be isolated from spacecraft perturbations through the use of a soft mount.

28. Man's gross movements such as push-offs should be restricted in both magnitude and frequency.

29. At least one special isolation technique should be evaluated in conjunction with the fine guidance experiment.

30. To maneuver in orbit without introducing attitude disturbances requires a centrally located center of gravity which can conveniently be achieved only if the telescope axis is concentric with the launch axis. On the other hand, configurations with the telescope axis perpendicular to the launch axis need not be deployed or assembled after launch. These two factors -- space assembly of longitudinally oriented telescopes and attitude control during maneuvering for laterally oriented telescopes -- are the principle considerations in telescope/spacecraft configuration.

31. The most likely arrangement in early AAP flights require that the ECS located in the Service Module is required to circulate atmosphere through the LEM Ascent stage into the telescope wall. Provision must be made to avoid dead zones in the circulation pattern.

32. To study the tradeoffs between shirt-sleeve accessibility to the telescope and the effects of mirror surface contamination, more information is needed about the rate and extend of contamination.

33. Three types of power systems were considered, oriented photovoltaic, unoriented photovoltaic, and radioisotope thermoelectric. The preferred system is the oriented photovoltaic.

34. The laser experiments should not be operated in synchronous orbit when the OTAES is in the shadow of the earth because of the high weight penalty that must be paid for the energy storage subsystem to supply power under dark conditions.

Recommendations

1. It is recommended that 15 space experiments be flown. These are:

   a. Optical Heterodyne Detection on Earth.
   b. Optical Heterodyne Detection on the Spacecraft.
   c. Direct Detection Space to Ground.
   d. Communication with 10 Megahertz Bandwidth.
   e. Precision Tracking of a Ground Beacon.
   f. Transfer Tracking from One Ground Station to Another.
   g. Point Ahead and Space-to-Ground-to-Space Loop Closure.
   h. Phase Correlation Measurements.
   i. Pulse Distortion Measurements.
   j. Primary Mirror Figure Test and Correction.
   k. Thin Mirror Nesting Principle and Erection and Alignment of Large Optics in Space.
   l. Fine Guidance.
   m. Comparison of Isolation Techniques.
   n. Interferometer System.
   o. Segmented Optics.

   The description of each of these experiments appears in the OTAES study report together with supporting analysis conceptual design.

2. A continued effort in defining new OTAES experiments should be maintained.

3. In particular, detector technology requires further investigation as an area in which fruitful space experiments might evolve.

4. Four candidate spacecraft are recommended for further study to identify the configuration which most nearly meets all of the requirements. These are:

   a. Modified Apollo Synchronous Spacecraft.
   b. Synchronous Spacecraft.
   c. Dual Mission Spacecraft.
   d. Near Earth Orbit LEM Spacecraft.

   These configurations are described in the OTAES study report.

5. Priority should be given to investigation of the LEM Ascent Stage for the OTAES missions.

6. A detailed study of the use of the Apollo spacecraft on a manned synchronous mission should be undertaken.

7. Four candidate missions are recommended for the OTAES program. These are: a manned synchronous mission, an unmanned synchronous mission, a manned low Earth orbit mission and a single launch dual mission combining the unmanned synchronous and manned low earth orbit missions.

8. A portion of this investigation should be cost effectiveness studies of these alternatives and of the effect of sequentially performing the proposed experiments.

9. These mission and spacecraft candidates should be investigated for the purpose of determining an optimum OTAES preliminary program plan.

10. An OTAES technical plan should be developed which will describe the tasks required in the following OTAES phase and a plan for accomplishing these tasks.

11. An OTAES preliminary facility plan should be developed which defines the nature and extent of the facilities required to accomplish the OTAES objectives.

12. An OTAES preliminary test plan should be developed which indicates the nature and extent of test and checkout activity necessary to accomplish the OTAES objectives.

13. An OTAES preliminary schedule should be prepared which will establish a feasible timing for OTAES development and will identify the critical paths in the development and the urgency of timing of the specific development tasks.

14. Begin funding of prerequisite IR&D efforts related to OTAES flight experiments based on indicated long-lead technologies.

15. An OTAES preliminary cost plan should be developed which will indicate the cost of the OTAES alternatives.

16. There should be continued definition of the projected optical technology needs in each of the application areas of astronomy, earth remote sensing, meteorology, and optical communications.

17. Initiate a study to identify those technologies not in specific support of flight experiments to complement the optical technology associated with flight experiments which results in further OTAES studies.

18. It is recommended that an overall optical technology program plan be explicitly detailed. This plan should indicate the relationship of space experiments and related ground based tests to other programs including those which do not include space testing.

19. Generate a study which indicates the impact and relationships of all other NASA optical technology development efforts on OTAES. These impacts and relationships should be expressed in terms of cost and time savings.

20. Although the experiment concepts described in the report are feasible, they are not necessarily optimum. In particular, a consideration of alternatives which would enhance the overall OTAES probability of success (insure maximum technological data) is needed. A series of conditional probability analyses are needed which, when assembled, will relate success in all flight phases (launch, injection, experiment, etc.) with mission, spacecraft, and experiment grouping alternatives.

21. Specific elements of the above generated reliability estimates should be compared to reliability estimates for accomplishing the technological experiment objective directly in the application without the intermediate step. Such a comparison would yield a quantification of the OTAES technological gain.

22. The technology advancements required to attain long range goals are of such magnitude and complexity that a technological quantum jump approach does not appear feasible. Consequently, space experiments are not only necessary to attain otherwise unavailable technological data but are also recommended to provide a logical step insuring continuous technology advancement toward future national space needs.

23. It is recommended that the high reliability standards of the manned space program be maintained in all the space science areas through the development of optimum technology so as to insure maximum national support of these future potential space goals.

24. The development of experiment justification should be continued and further supported by the new analyses recommended as necessary in the continuation of OTAES work.

25. The feasibility of implementing some of the recommended experiments should be explored in greater detail. For instance, a control and stabilization simulation, a dynamic analysis, and a thermal analysis should be performed on the integrated configurations developed in this part of the OTAES study.

26. Since the experiment availability is largely paced by the telescope development early design definition of the telescopes is recommended. Again this points out the early need for the analysis in the previous recommendation.

27. The influence of contaminate particle size and distribution on the mirror characteristics should be determined so the extend of degradation can be estimated.

28. More detailed analyses are required to determine the exact influence of thruster location on the performance of solar cells, optical viewports, sensors, and optical subsystems in the telescope well.

29. A detailed analyses of secondary batteries that will be used in the system, the power conditioning, and distribution subsystems should be initiated; and there should be further detailed study in the area of the power system, experiment interface, and the power system spacecraft interface.

30. Once the mission profile is established a study should be undertaken to determine the size and type of ECS storage system for pressurizing the modules, cabin, and the telescope wells. If a large number of repressurizations are necessary, a study should be conducted to define what savings, if any, can be realized by pumping down the compartments prior to venting.

31. A detailed analysis of the contributing factors leading to spatial resolution degradation should be performed.

32. Further definition of OTAES support requirements is needed such as the ground station, data handling, etc.

33. Further definition of the man/experiment interface is necessary to coincide with the level of experiment conceptual detail and the integrated experiment groupings developed in Part I.